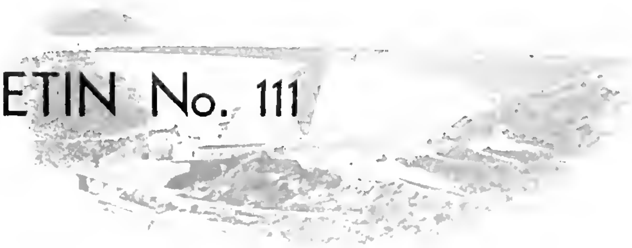
THE RESOURCES AGENCY OF CALIFORNIA

Department of Water Resources



BULLETIN No. 111

SACRAMENTO RIVER WATER POLLUTION SURVEY

AUGUST 1962

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Administrator
The Resources Agency of California
and Director
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THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

1120 N STREET, SACRAMENTO

August 8, 1962

Honorable Edmund G. Brown, Governor, and
Members of the Legislature of the
State of California

Gentlemen:

I have the honor to transmit herewith Bulletin No. 111, entitled, "Sacramento River Water Pollution Survey." The investigation described in the report was authorized by Chapter 1909, Statutes of 1959 and by subsequent actions providing for appropriations from the general fund.

This report concludes that water quality of the Sacramento River is eminently satisfactory for present beneficial uses. The increases in dissolved mineral concentrations that do occur are related to irrigation practices. Below Sacramento, dissolved oxygen levels are approaching the minimum values set for fish.

The future increased utilization of Sacramento River waters requires an adequate program of water quality management. To this end, specific recommendations for water quality monitoring and for special investigations are presented.

Sincerely yours,

William E Warne

Director

ACKNOWLEDGMENT

The Sacramento River Water Pollution Survey was greatly implemented by the valuable assistance and cooperation of several agencies of the Federal Government and of the State of California, Cities, Counties, and private companies and individuals.

The participation, cooperation, and assistance of the following organizations is particularly acknowledged:

Advisory Committee composed of:

Central Valley Regional Water Pollution Control Board (No. 5)	Col. J. S. Gorlinski Charles T. Carnahan
California Department of Fish and Game	David C. Joseph
California Department of Public Health	Paul C. Ward Arnold E. Greenberg
U. S. Public Health Service	F. W. Kittrell William M. Ingram H. P. Kramer H. W. Jackson
U. S. Navy, 12th Naval District	Commander C. W. Heck Warrant Officer Sullivan
U. S. Bureau of Reclamation	
U. S. Geological Survey	
Tennessee Valley Authority	M. A. Churchill
California Department of Fish and Game	Ellis Berry
California Department of Natural Resources Division of Small Craft Harbors	
City of Red Bluff	H. A. Eaton
City of Rio Vista	Raymond Barth
City of Isleton	Joseph Barbutt
City of Sacramento, Department of Water and Sewers	Raymond Jones Harold Jeffery
City of Redding	Hal E. Marron Robert Gullixson
Sacramento County Sheriff's Office	Lt. Parker Smith
West Sacramento Sanitary District	Walter Moniz
American River Junior College	Kenneth D. Boettcher
Miller Park Boat Harbor	Bud Silva
American Crystal Sugar Company, Clarksburg	C. W. Hogge
Diamond National Corporation at Red Bluff	Ernest Develter

Special mention is made of the following individuals who loaned boats and equipment to the investigation: Neal Butler, W. D. Cofer, Walter Dorwaldt, C. D. Hayes, Noel Helphenstine, Earl Van Hoorbeke, William J. Hunter, Walter Johnson, Raymond Kapusta, Clay Meyer, W. Q. Miller, Grover E. Oaks, S. V. Scott, Harry Webb, Jack Woods, and Sebastian Yturralde.

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DEPARTMENT OF WATER RESOURCES

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WILLIAM M. CARAH
Executive Secretary

GEORGE B. GLEASON
Principal Engineer

AUTHORIZATION

The Sacramento River Water Pollution Survey was authorized by the California State Legislature in Chapter 1909, Statutes of 1949. This, and subsequent legislative section, provided for appropriations from the general fund for the conduct of the investigation. Statutory authority for pollution investigations derives from Section 229 of the Water Code.

CHAPTER I. SUMMARY AND RECOMMENDATIONS

The Sacramento River Water Pollution Survey was authorized by the California Legislature in 1959 to provide guides for maintaining adequate levels of water quality in the river. Specific objectives included:

1. Determine present (base-line) quality conditions in the river from Shasta Dam to Mayberry Slough.
2. Determine sources and effects of present degradation of water quality.
3. Establish a continuing water quality monitoring program.
4. Recommend future studies and water quality management practices for the Sacramento River.

Intensive studies of the river and influent flows were made from April 1960 through June 1961. More than 8,000 samples of water were analyzed for oxygen content, temperature, and bacteria. Concentrations of dissolved minerals were determined for over 3,000 samples. Evaluation of these and related data met the four objectives; the first two are discussed in the findings and the last two are presented as recommendations.

Findings

Water quality of the Sacramento River during 1960-61 was eminently satisfactory for present beneficial uses. However, a few danger signals are beginning to appear. If the greater quantities of wastes which will be discharged in the future are handled by present methods serious water quality problems can be expected. Specific findings are summarized below:

(1) Between 1960 and 1990, Sacramento Valley populations are expected to increase from 1,142,420 to 3,092,400, irrigated lands from 1,900,000 to 2,747,000 acres, and total water demand from 7,468,000 to 10,688,000 acre-feet per year.

(2) During 1960, five domestic water systems supplied an average total of 53 million gallons per day of river water to about 272,000 people.

(3) Present diversions of river water for agriculture amount to some three million acre-feet per year, divided almost equally between the Sacramento Valley and, by means of the Delta-Mendota Canal, the San Joaquin Valley.

(4) Recreational use of the river involves many thousands of people during holidays and the expenditure of millions of dollars annually. Water contact sports are concentrated near population centers where sewage discharges causes significant bacterial populations in the water. Since sport fishing, commercial fishing, and wildlife habitats are dependent upon the river, minimum reservoir releases are specified for fish protection.

(5) The river channel is maintained at a minimum depth of ten feet below Sacramento and six feet upstream to Colusa by a minimum flow of 5,000 cubic feet per second near Wilkins Slough. Commercial shipping amounted to about 5,500,000 tons in 1960. This is expected to triple by 1990.

(6) Sewage treatment plant effluents are discharged directly to the river by the Cities of Redding, Red Bluff, Corning, West Sacramento, Sacramento, Isleton, and Rio Vista. All plants provide only primary treatment. About 90 percent of the total 55.3 million gallons per day of sewage flow is through the Sacramento main plant. Within the near future,

additional plants in the Sacramento area, with an aggregate design capacity of 21.5 million gallons per day, will be discharging secondary effluent to the river and its tributaries.

(7) Most industries discharge to municipal sewerage systems. The two major direct discharges to the river are from a wood products plant near Red Bluff and a sugar beet processing plant near Clarksburg. The former causes no measureable effect in the river and the loading from the latter is superimposed upon the effects of discharges from the Sacramento area.

(8) Irrigation return flows of about 900,000 acre-feet per year are largely discharged to the 20-mile reach above the Feather River.

(9) Releases from Shasta Dam repel sea water in the Delta so that salt water incursions into the river have been restricted to the lowest seven miles since 1949.

(10) The present mineral quality of the Sacramento River is excellent with total dissolved solids ranging generally between 75 and 100 parts per million in the upper reach and between 100 and 150 parts at Sacramento; the increases are primarily due to irrigation return flows.

(11) The bacteriological quality of the river reflects the discharge of sewage treatment plant effluents to which varying amounts of chlorine have been added. River water used for domestic purposes accordingly requires treatment for removal of bacteria as well as occasional turbidity, tastes, and odors.

(12) Algae populations in the river vary seasonally and typically increase with distance from Shasta Dam as winter temperature rise and as nutrients from tributaries and waste discharges are added.

(13) The occurrence of bottom organisms in the river is controlled by natural conditions unrelated to waste discharges.

(14) Dissolved oxygen levels in the river are adequate for the multiple uses to which river water is put. The most critical oxygen conditions in the river are, and will continue to be, found below Sacramento; the minimum observed concentration of 5.2 parts per million shows that the minimum of five parts established for fish is in jeopardy. Additional data are required to adequately determine the waste assimilative capacity of the river.

(15) The present water quality monitoring program shows conditions in the river; it does not permit sufficiently precise determination of the present causes of water quality changes or of probable future water quality conditions. These aspects of water quality management can be provided by monitoring the tributaries and computing quality in the river. Although the initial effort will be an expansion of the program, ultimate annual expenditures will be reduced.

(16) Investigations similar in scope to the Sacramento River Water Pollution Survey require about two man-days on data evaluation for each man-day in the field, concurrent with the data collection phase. During the final data evaluation and report writing phase, an additional two man-days in the office are needed for each man-day in the field. These ratios do not include laboratory requirements.

Recommendations

In order to minimize future degradation of water quality in the Sacramento River due to increased utilization of the water, it is recommended that:

(1) The present departmental surface water quality monitoring program for mineral constituents in the river be changed to provide data on tributaries and waste discharges and that mineral quality of the river be computed.

(2) Departmental requirements for information on bacteriological and biological conditions, organic materials, and dissolved oxygen be met by conducting intensive short-term surveys, and by installing continuous dissolved oxygen analyzers at Sacramento and Walnut Grove.

(3) In addition to the basic program outlined above, additional special studies be made as follows:

(a) Analyze continuous conductivity recorder data obtained during the present investigation to characterize vertical and longitudinal mixing. Evaluate the use of conductivity recorders to investigate travel times, flow distribution, and mixing in waterways of the Sacramento-San Joaquin Delta.

(b) Conduct a special study of water temperatures and heat balances throughout the Sacramento River systems, including the Sacramento-San Joaquin Delta, to provide criteria for reservoir operations, to estimate the capacity of the river to assimilate thermal pollution, and to provide data on mixing.

(c) Conduct a special two-year investigation of oxygen relationships in the river between Sacramento and Rio Vista consisting of two-day intensive surveys at monthly intervals; this will provide correlation factors for predicting future dissolved oxygen levels.

(d) After the revised monitoring program for mineral constituents has been in operation for one year, predict future mineral quality conditions in the Sacramento River. Make subsequent predictions at about two-year intervals which include consideration of a Sacramento Valley master drainage system.

CHAPTER II. INTRODUCTION

Objectives and Scope of Investigation

The principal objective of the Sacramento River Water Pollution Survey was to satisfy the requirements of various agencies responsible for or interested in the field of water quality by establishing a comprehensive knowledge of the many interrelated variables which influence water quality in the Sacramento River. The survey was planned to provide the information necessary to establish suitable guides for use in maintaining adequate levels of water quality in the Sacramento River.

To implement the general objectives stated above, the investigation provided for determination of:

1. Present (base-line) quality conditions in the Sacramento River from Shasta Dam to Mayberry Slough.

2. Detailed information on present sources of degradation and their influence on water quality

3. A continuing water quality monitoring program.

4. Recommendations for future studies and for quality management practices which would maintain optimum water quality in the Sacramento River.

These objectives cross the traditional boundaries of several agencies. Accordingly, full-time professional services by personnel of the California Department of Public Health and the California Department of Fish and Game were obtained by inter-agency agreements. In addition, the Central Valley Regional Water Pollution Control Board (No. 5) and personnel of the United States Public Health Service, Robert A. Taft Sanitary Engineering Center served in advisory capacities.

Area of Investigation

The Sacramento River Water Pollution Survey was conducted over the 300-mile reach between Keswick Reservoir, which provides afterbay regulation of releases from Shasta Dam, and the confluence of the Sacramento and San Joaquin Rivers at Mayberry Slough (Plate 1).

The river may be divided into three major reaches. In the upper reach between Keswick (mile 300) and Hamilton City (mile 200), the river flows through rolling to mountainous country in a steep, well-defined channel with many rapids. Inflows from permanent and intermittent streams and from rising ground water occur in this reach.

Throughout the middle reach, between Hamilton City and Sacramento (mile 60), the river follows a meandering course through a deep and wide alluvial fill and is controlled by extensive levee systems and flood-control bypasses. Most of the side streams in the upper portion of this reach are diverted through Colusa Basin to the west and through Butte Slough and Sutter Basin to the east. There are a number of irrigation diversions and returns. The two major tributaries, the Feather and American Rivers, enter at miles 80 and 61, respectively.

The lower reach, between Sacramento and Mayberry Slough, is characterized by distributary flows through various waterways in the Sacramento-San Joaquin Delta. The major diversion from the river through the Delta Cross Channel (mile 27.4) provides water to the San Joaquin Valley through the U. S. Bureau of Reclamation's Delta-Mendota Canal. Tidal action causes flow reversals as far upstream as Clarksburg (mile 43) and affects water levels and velocities as far upstream as Verona (mile 80). The maximum flow reversals occur in the vicinity of Isleton (mile 19).

Physiography. The Sacramento River drains an area of over 26,000 square miles as shown on Plate 2. The river is fed by 39 streams originating in the Coast Ranges to the west, the Klamath Mountains to the northwest, the Cascade Range and Modoc Plateau to the northeast, and the Sierra Nevada to the east. Elevations range from below sea level in the Sacramento-San Joaquin Delta to 14,161 feet at Mount Shasta.

Geology. The major inflow to Shasta Dam comes from the Modoc Plateau which is underlain by thick accumulations of lava with many small volcanic cones and from the Cascade Range which consists primarily of a chain of volcanic cones.

Shasta Lake is located in the extremely rugged Klamath Mountains which are comprised of a wide variety of deeply weathered marine sediments, some of which have been metamorphosed, and granitic rocks.

The Coast Ranges are a system of essentially parallel ranges consisting primarily of old marine sediments.

The Sierra Nevada is a tilted block with a gentle westerly slope. In the foothills, the rocks are mostly metamorphic while massive granites are found in the high Sierra.

The Sacramento Valley occupies the northern portion of the Central Valley and is underlain by a thick series of water-bearing sediments. These sediments are over 2,000 feet thick near the Sacramento River and thin laterally towards the sides of the valley.

Soils. The soils of the Sacramento Valley vary in their physical and chemical characteristics according to their sources, ages, and degree of development. These soils can be divided into four broad groups: (1) old valley fillings, (2) basin soils, (3) recent alluvium, and (4) organic soils.

(1) Soils derived from old valley fillings and remanents of former alluvial fans are found along both sides of the valley floor. Leaching and other soil forming processes have brought about soils varying from those with dense claypan or cemented hardpan subsoils, to those with moderately compact subsoils. These soils are generally suitable for shallow to medium-deep rooted crops.

(2) Basin soils have developed from the sediments deposited by overflow water in low-lying basin areas between the alluvial fans and the major river flood plains. These soils are normally fine textured and, due to limited or restricted drainage, accumulation of soluble salts and exchangeable sodium is often present. The basin soils are suitable for many climatically adapted medium and shallow rooted crops.

(3) Recent alluvial soils occupy alluvial fans and flood plains adjacent to major and minor stream channels. In general, these soils are deep, friable, and medium textured and have undergone little or no change in their profile characteristics since deposition. Where adequately drained, these soils have wide crop adaptability and are highly valued as agricultural lands.

(4) Organic soils resulting from decomposition of tules and other aquatic plants are found in the Sacramento-San Joaquin Delta. These soils have a high agricultural value for specific crops when properly drained and managed.

Climate. The climate of the Sacramento Valley is characterized by hot, dry summers and mild winters. The rainy season extends from November through April. Mean annual rainfall varies from about 15 inches in the Sacramento-San Joaquin Delta to 22 inches at Red Bluff and 34 inches at Shasta Dam. Mean monthly temperatures in the basin vary from about

39°F in the winter to 73°F in the summer with a mean annual temperature of about 55°F. The average annual evaporation in the valley varies from about 50 to 75 inches. The valley is normally free from frost for a period of seven to eight months each year. For the most part, the summer and fall seasons exhibit an almost continuous succession of sunny days.

In the mountainous areas, the major portion of precipitation consists of heavy snowfall in the winter months. During late spring and early summer, snowmelt supplies the streams tributary to the Sacramento River. Near Donner Pass, in the Yuba River watershed, records indicate snow depths as great as 375 inches in 1880. The depth during 1881 was 40 inches, the minimum for the period of record.

Data Collection Programs

Field programs were conducted during the period April 1960 through June 1961 to provide data on hydrology; physical, chemical, and bacteriological quality of the water; oxygen relationships; stream biology; and the effects of tributaries and waste discharges on these characteristics. Plate 1 shows the locations of sampling stations.

Monthly determinations of physical and chemical characteristics, algae and other plankton, and bottom life were made throughout the river. Waste discharges and tributary flows were analyzed monthly for mineral and organic constituents. Continuous records of, or daily sampling for, mineral constituents were made at key locations.

Intensive sampling surveys were conducted in the upper reach (mile 297.3-184.5) in June and October 1960, in the middle reach (mile 184.5-62.6) in September 1960 and May 1961, and in the lower reach (mile 62.6-4.0) in June, late August, and October 1960. During the May and June periods, runoff from snowmelt was essentially complete, and irrigation

returns were negligible. In late August, irrigation returns were nominal and seasonal waste discharges from food processing plants were at a peak. Maximum irrigation returns from rice fields occurred in September. In October, reservoir releases and irrigation diversions were at a minimum and highly mineralized irrigation waters were returned to the river. Each of the intensive surveys was conducted over a four-day period when samples were taken at three-hour intervals from closely spaced river stations and waste discharges. Samples were analyzed for bacteriological quality, dissolved oxygen, and organic content as indicated by the biochemical oxygen demand.

Analyses were made in accordance with the 11th edition of "Standard Methods for the Examination of Water and Waste Water" (2). Temperature, dissolved oxygen, acidity or alkalinity as measured by pH, and total dissolved minerals as measured by electrical conductivity, were determined in the field. Chemical analyses were performed at the department's laboratory at Bryte, near Sacramento. Bacteriological analyses and algae identification and enumeration were performed by the State Department of Public Health using a mobile laboratory and at the Berkeley laboratories, respectively. Bottom organisms were identified by a State Department of Fish and Game specialist at the Bryte laboratory of the Department of Water Resources.

Scope of Report

This report summarizes the findings of the Sacramento River Water Pollution Survey and presents recommendations for future water quality monitoring and additional studies necessary for water quality management in the Sacramento River. Detailed technical discussions and basic data are presented in separately bound appendices as follows:

Appendix A. "Hydrography, Hydrology, and Water Utilization," by the Department of Water Resources

Appendix B. "Water Quality," by the Department of Water Resources

Appendix C. "Public Health Aspects," by the Department of Public Health

Appendix D. "Benthic Biology," by the Department of Fish and Game.

Related Investigations and Reports

A large number of reports containing information and data pertinent to evaluation of water quality of the Sacramento River were utilized during the current investigation. Complete lists and references are included in appendices to this bulletin. The following partial listing includes the reports of major importance and those which are cited in this bulletin. Reference is made to these reports in the text by means of numbers in specific parentheses; e.g., (1).

(1) Academy of Natural Sciences of Philadelphia, Department of Limnology. "Sacramento River, Keswick Reservoir and Vicinity." July 1956.

(2) American Public Health Association. "Standard Methods for the Examination of Water and Wastewater." 11th Edition. 1960.

(3) California State Department of Public Health, Bureau of Sanitary Engineering. Report No. 242. "To the California State Board of Health on Quality of Sacramento River Water at Sacramento." July 28, 1920.

(4) ----. Report No. 244. "To the California State Board of Health on Quality of Sacramento River Water at Sacramento." August 4, 1920.

(5) ----. Office Report, "A Study of the Sacramento River as Influenced by Waste Discharges from the American Crystal Sugar Corporation, Clarksburg, California." 1950.

(6) ----. Office Report, "Enterprise Public Utility District Sanitary Survey." December 9, 1953.

(7) ----. Office Report, "Redding Sanitary Survey." January 10, 1955.

(8) ----. Office Report, "Sacramento River Survey - October 1956." October 1956.

(9) ----. Office Report, "Recommendations for Operating the Red Bluff Sewage Treatment Plant." September 10, 1959.

(10) ----. Memorandum, "Sewage and Sewage Treatment of the City of Rio Vista." May 16, 1960.

(11) ----. Memorandum, "Sacramento River Survey - September, 1960." September 6, 1960.

(12) ----. Monthly Notes, "Report of Plant Inspections at Corning." July 29, 1959; November 5, 1959; June 1, 1960; February 6, 1961.

(13) ----. Office Report, "Report on the City of Redding Sewage Discharge Effects on Sacramento River Water and Downstream Water Uses." May 1961.

(14) ----. Office Report, "City of Sacramento Municipal Water System." June 1961.

(15) ----. Office Report, "Progress Report on the Quality of the Lower Sacramento River Water and Domestic Sewage Effluent Discharges." April 1957.

(16) ----. Memorandum, "Bacteriological Quality of the Lower Sacramento River." May 3, 1957.

(17) ----. Memorandum, "West Sacramento Sanitary District - Sewage Disposal Expansion Project." November 4, 1957.

(18) ----. Memorandum, "Appraisal of Red Bluff Sewage Treatment Plant Operations." August 20, 1958.

(19) ----. Monthly Notes, "Reports of Plant Inspections at Isleton." April 9, 1958; September 30, 1958.

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(21) ----. Office Report, "City of Vallejo Water Supply System, Report of the Sanitary Engineering Survey." September 1959.

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(23) ----. "Sacramento River Basin." Bulletin No. 26. 1931.

(24) ----. "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay." Bulletin No. 27. 1931.

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(26) ----. "The California Water Plan." Bulletin No. 3. May 1957.

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(28) ----. "Quality of Surface Waters in California - 1957." Bulletin No. 65-57. December 1960.

(29) ----. "Quality of Surface Waters in California - 1958." Bulletin No. 65-58. December 1960.

(30) ----. "Surface Water Flow for 1959." Bulletin No. 23-59. May 1961.

(31) ----. "Quality of Surface Waters in California - 1959." Bulletin No. 65-59. July 1961.

(32) ----. "Surface Water Flow for 1960." Bulletin No. 23-60. September 1961.

(33) California State Water Pollution Control Board. "Water Quality Criteria." State Water Pollution Control Board Publication No. 3. 1952.

(34) California State Water Resources Board. "Water Resources in California." Bulletin No. 1. 1951.

(35) Central Valley Regional Water Pollution Control Board. "Water Pollution Study - Sacramento River Watershed." 1955.

(36) Churchill, M. A. and Buckingham, R. A. "Statistical Method for Analysis of Stream Purification Capacity." Sewage and Industrial Wastes, 28, 4, 517. April 1956.

(37) Churchill, M. A., Elmore, H. L., and Buckingham, R. A. "The Prediction of Stream Reaeration Rates." Division of Health and Safety, Tennessee Valley Authority Presented at National Convention of ASCE. October 16 - 20, 1961. New York.

(38) Odum, H. T. "Primary Production in Flowing Waters." Limnology and Oceanography. Volume 1, No. 2. pp. 102-117. April 1956.

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(42) Streeter, H. W. "Measures of Natural Oxidation in Polluted Streams. II. The Reaeration Factor and Oxygen Balance." Stream Pollution. Sewage Works Journal. Volume 7, No. 3. p. 534. May 1935.

(43) Tsivoglou, E. C. "Discussion of Stream Data Applied to Waste Treatment Plant Design." Technical Report W-58-2. U. S. Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati. 1958.

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CHAPTER III. HYDROLOGY

The hydrographic and hydrologic features of the Sacramento River were determined from previously existing data and from measurements taken during the course of the present investigation. The minimum flows expected under present and future conditions govern the amounts of dilution available for various discharges.

Minimum Flows

Minimum flows in the Sacramento River under present conditions of development were determined on the basis of the 1921-41 base period, using diversions for the 1953-54 water year. Present conditions include projects operating or under construction in 1961 except for the Sacramento Municipal Utility District's Upper American River Development and the Bureau of Reclamation's Corning Canal.

Future conditions of development include all of those projects and demands as outlined in "Agreement Between the United States of America and the Department of Water Resources of the State of California for the Coordinated Operation of the Federal Central Valley Project and the State Feather River and Delta Diversion Projects," May 16, 1960. Development includes the Trinity River Diversion, Whiskeytown Reservoir Project (Clear Creek), Corning Canal, Tehama-Colusa Canal, Black Butte Reservoir Project (Stony Creek), Oroville Reservoir (Feather River), and the Folsom South Canal in addition to all presently operating development. It is expected that these developments will be in operation by the year 1990.

Diversions used in the future conditions study were compiled from existing water rights on the Sacramento River. These water rights quantities were employed in the department's Sacramento River Trial

Distribution Studies and have been published in a joint report entitled "Report on 1956 Cooperative Study Program--Water Use and Water Rights Along Sacramento River and in Sacramento-San Joaquin Delta," March 1957, and in supplements on hydrology and water rights by the U. S. Bureau of Reclamation, the State Department of Water Resources and the Sacramento River and Delta Water Association.

Irrigation return flows for both present and future conditions were estimated as a percentage of the diversions for each separate river reach. Percentages were assumed to be the same for both present and future conditions. Return flows from diversions were considered to be negligible from November 1 to March 31.

The minimum navigation requirement for the vicinity of Wilkins Slough (about mile 118) employed in the future conditions study was 4,000 cfs, with a 1,000 cfs deficiency allowable under certain conditions of project inflow, project and nonproject demands, and combined storage in project reservoirs.

The results of the minimum flow studies are shown in Table 1. Minimum flow rates in cubic feet per second are tabulated for each month of the year under both present and future conditions of development. Flows represent the minimum conditions to be expected for that month of the year. Daily flows could drop below the specified amounts while control measures are being taken at any of the various projects.

The results listed in Table 1 are presented only as a guide for water quality management planning. They are valid for the particular operating conditions and assumptions outlined previously. It is expected that the operations plan will be revised from time to time so that better estimates of minimum flows, particularly downstream from the Feather River, will be available.

Table 1

HYDROLOGY
MINIMUM FLOWS - SACRAMENTO RIVER
Cubic Feet Per Second
(Based on Monthly Flows for the Period 1921-22 to 1940-41)

PRESENT CONDITIONS OF DEVELOPMENT

Reach No.	River Mile	Reach Description	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1	300-297	Keswick to Anderson-Cottonwood I. D. Diversion	4,600	3,900	2,600	2,600	2,600	2,300	2,400	4,400	6,400	7,900	8,400	5,900
2	297-270	Anderson-Cottonwood I. D. Diversion to Battle Creek	4,300	3,800	2,600	2,600	2,600	2,300	2,100	4,000	6,000	7,500	8,100	5,600
3	270-242	Battle Creek to Corning and Tehama-Colusa Canal Diversion	5,400	5,400	4,500	5,300	4,300	3,300	4,900	7,100	7,600	8,600	8,800	6,300
4	242-205	Corning and Tehama-Colusa Canal Diversions Glenn-Colusa I. D. Diversion	5,400	5,400	4,500	5,300	4,300	3,300	5,000	7,500	7,700	8,600	8,800	6,300
5	205-164	Glenn-Colusa I. D. Diversion to R. D. 1004 Diversion	5,000	4,900	4,900	4,800	4,900	4,700	5,300	6,800	6,900	7,100	6,900	5,800
6	164-119	R. D. 1004 Diversion to Sutter Mutual Water Company Diversion	5,100	5,000	5,000	5,000	5,000	5,000	5,400	6,600	6,500	6,500	6,400	5,700
7	119- 90	Sutter Mutual Water Company Diversion to Colusa Basin Drain	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
8	90- 80	Colusa Basin Drain to Feather River	5,700	5,000	5,000	5,000	5,000	5,000	5,000	5,800	5,500	5,200	5,600	6,400
9	80- 60	Feather River to American River	7,400	6,500	6,500	7,000	8,000	8,200	9,400	7,900	6,900	6,300	6,900	7,900
10	60- 33	American River to Steamboat Slough	7,900	7,000	7,500	7,400	8,900	8,600	9,700	8,600	9,400	9,500	10,300	9,300

FUTURE CONDITIONS OF DEVELOPMENT

Reach No.	River Mile	Reach Description	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1	300-297	Keswick to Anderson-Cottonwood I. D. Diversion	4,000	3,900	2,600	2,600	2,600	2,300	2,300	4,500	6,900	7,300	9,100	5,300
2	297-270	Anderson-Cottonwood I. D. Diversion to Battle Creek	3,700	3,900	2,600	2,600	2,600	2,300	2,100	4,200	6,500	6,900	8,800	5,000
3	270-242	Battle Creek to Corning and Tehama-Colusa Canal Diversions	4,200	4,400	3,200	3,800	4,300	3,300	4,200	5,200	7,700	7,300	9,100	5,400
4	242-205	Corning and Tehama-Colusa Canal Diversions Glenn-Colusa I. D. Diversion	3,700	4,400	3,200	3,800	4,300	3,200	3,900	4,300	6,500	5,900	7,900	4,700
5	205-164	Glenn-Colusa I. D. Diversion to R. D. 1004 Diversion	3,000	4,100	3,600	4,500	4,900	3,800	3,800	4,900	4,900	5,400	5,200	3,800
6	164-119	R. D. 1004 Diversion to Sutter Mutual Water Company Diversion	3,100	4,200	3,700	4,600	5,100	4,000	3,700	4,400	4,500	4,500	4,400	3,600
7	119- 90	Sutter Mutual Water Company Diversion to Colusa Basin Drain	3,000	4,200	3,700	4,600	5,100	4,000	3,000	3,000	3,100	3,000	3,000	3,000
8	90- 80	Colusa Basin Drain to Feather River	3,700	4,200	3,700	4,600	5,100	4,000	3,100	3,500	3,500	3,200	3,600	4,000
9	80- 60	Feather River to American River	6,700	5,500	5,100	5,800	6,500	7,100	4,500	4,500	6,000	7,900	10,000	10,000
10	60- 33	American River to Steamboat Slough	6,900	5,900	5,400	6,000	6,600	7,200	4,600	4,600	6,500	7,900	10,000	10,100

CHAPTER IV. WATER UTILIZATION

The major sources of California's waters are located in the northern part of the State where the waters are largely wasted to the ocean. Central and southern regions, with the bulk of the population and rich in productive land areas, lack sufficient water supplies. Over 70 percent of the stream flow in California occurs north of a line drawn through Sacramento. The streams of the Sacramento basin carry about 32 percent of the total for the State. On the other hand, 77 percent of the present consumptive water requirement and 80 percent of the future ultimate requirement is south of Sacramento.

The Sacramento Valley covers an area of about 5,000 square miles and averages about 30 miles in width. Table 2 summarizes the present and predicted future land and water use patterns:

Table 2

PRESENT AND FUTURE LAND AND WATER USE IN SACRAMENTO VALLEY

	1960	1990
Population	1,142,420	3,092,400
Urban area, acres	143,000	336,000
Urban water demand, acre-feet per year	225,000	745,000
Irrigated land, acres	1,900,000	2,747,000
Irrigation water demand, acre-feet per year	7,243,000	9,943,000

Domestic Water Systems

Five domestic water systems presently derive all or most of their water from the Sacramento River. In the Redding area, the City of Redding and the Rockaway Water Company pump their total supplies from the river intakes and Enterprise Public Utility District supplies come

from an infiltration gallery along the river and from two wells. The City of Sacramento derives 80 to 85 percent of its supply from the river. The Vallejo water system serves water from Cache Slough to that city and nearby military installations. Table 3 lists the 1960 use of river water in millions of gallons per day (MGD):

Table 3

DOMESTIC USE OF SACRAMENTO RIVER WATER, 1960

	City of Redding	Rockaway Water Company	Enterprise Public Utility	City of Sacramento	City of Vallejo
Estimated population	12,500	84	4,700	139,400	115,000
Average MGD	3.74	0.008	---	37.7	11.9
Maximum MGD	9.27	0.015	---	71.0	17.3
Average summer MGD	---	---	0.25	---	---
Average winter MGD	---	---	0.038	---	---
Average gallons/capita/day	299	90	---	259	103

The major additional development of domestic supplies will occur at Sacramento late in 1962 when a 14 MGD Ranney collector is scheduled to be placed in service.

Irrigation Supply

In 1960, almost three million acre-feet of Sacramento River water were diverted for agricultural use. Fifty-two percent of the total was used in the Sacramento Valley and the balance was delivered through the Bureau of Reclamation's Delta-Mendota Canal to the San Joaquin Valley as shown in Table 4:

Table 4

MAJOR IRRIGATION DIVERSIONS FROM THE SACRAMENTO RIVER, 1960

River Mile	Water User	Total Diversion, acre-feet	Maximum Monthly Diversion, cfs
297.7R	Anderson-Cottonwood Irrigation District	174,700	395
205.1R	Glenn-Colusa Irrigation District	768,100	2,320
205.0R	Jacinto Irrigation District	85,600	175
174.1R	Princeton-Codora-Glenn Irridation District	65,600	150
118.9L	Sutter Mutual Water Company	213,100	760
118.3R	Reclamation District No. 108	95,100	350
99.0R	Reclamation District No. 2047	64,400	220
71.2R	Woodland Farms, Incorporated	65,200	260
27.3L	Delta-Mendota Canal	1,389,200*	3,925*

* Including minor amount from San Joaquin River.

The 1.5 million acre-feet diverted in the Sacramento Valley constitute about 20 percent of the requirements shown on Table 2; the balance is provided by other streams and local ground waters and by re-use of some of the drainage water.

Drainage waters generally have specific conductance values between 300 and 600 micromhos during the irrigation season and from 600 to 1200 during the winter, depending upon the particular area. Supply waters have conductances generally ranging from about 100 to 200 for surface waters and 200 to 500 for ground waters. The increases of conductance and, accordingly, of dissolved solids, during irrigation are caused by loss of water through evaporation from water surfaces and transpiration through plants and by addition of minerals leached from the soil.

A special study was made to determine the effects of application of a weedicide on a rice field. Twelve ounces per acre of MCPA (2-methyl, 4-chlorophenoxyacetic acid) were applied to the field which was flooded to a depth of about four inches; this is equivalent to a concentration of one part per million. Water which drained from the field between two and ten days after the application had an average concentration of one part per billion. Although the initial concentration of the weedicide was undoubtedly higher, small and apparently healthy fish were observed in the drain throughout the period. This indicates that the MCPA had no significant effect upon the aquatic life in the ditch.

Recreation

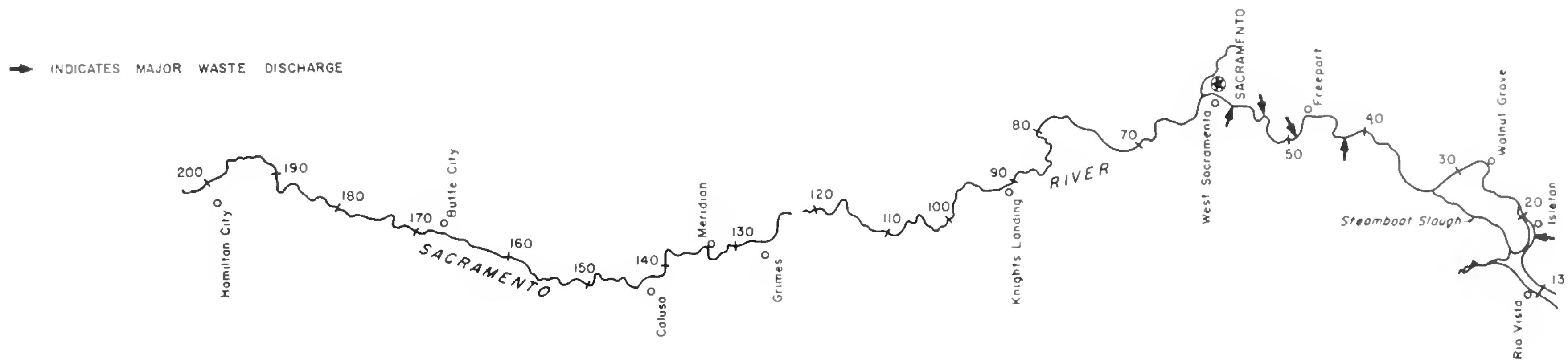
The Sacramento River is ideally suited for pleasure boating and boat fishing. A channel is maintained upstream to Colusa which will accommodate large boats and small boats can navigate throughout the river. Fishing boats can be rented or launched in almost every section of the river. There are approximately 68 public landings, parks, resorts and harbors that provide boating and fishing facilities and many offer overnight accommodations. There are long stretches where the tree-lined river passes through primitive areas adding to the esthetic enjoyment of boating. Other recreational activities such as swimming, wading, and water-skiing are collectively considered as water-contact sports. The public health significance of water-contact sports is discussed in the next chapter.

Downstream from Sacramento, floating restaurants with docking facilities are available for public use. At Walnut Grove, new docking facilities are being constructed to serve the boating public at a recently renovated hotel and restaurant. Large marinas at Rio Vista and near

Isleton have recently expanded their facilities, and a new, large park and marina is planned north of Colusa.

A survey of recreational activities on the river between Hamilton City and Rio Vista, including Steamboat Slough between Courtland and Rio Vista, was made by boat on Labor Day weekend, September 3 - 5, 1960. The results of this survey are summarized on Figure 1. A total of 2,338 people were observed. This integrates individual observations along the river, and may be assumed to reflect instantaneous daytime recreational activity. The actual number of people who used the river was undoubtedly several times greater as indicated by the ratio of total boats (2,584) to boats in use (628). It is not possible to estimate the additional number of boats which were launched from trailers during the weekend but which were not observed. A total of 43 resorts, public landings, camping areas and parks were observed. There were 90 private docks, fishing floats and boat sheds.

Information on boating activities from Anderson to Butte City was obtained from surveys made by the State Department of Public Health in 1956 and 1960. In these surveys, information on the uses of the river was obtained from resort owners along the river. The findings of these surveys are summarized in Table 5 which lists the maximum number of persons and boats for a single day during the recreational season. It can be seen that the number of privately owned boats berthed at the resorts or launched from trailers almost doubled during the four-year period. The number of persons boating and fishing from boats increased proportionally.



RIVER MILES

	200–190	190–180	180–170	170–160	160–150	150–140	140–130	130–120	120–110	110–100	100–90	90–80	80–70	70–60	60–50	50–40	40–30	30–20	20–13
BOATS																			
ANCHORED	123	2	23	40	39	41	112	73	2	7	3	6	140	132	703	160	119	90	139
PLEASURE	5	4	0	0	1	7	4	4	1	5	7	6	31	29	113	16	40	59	57
FISHING	7	4	3	0	7	17	50	24	6	1	4	1	17	7	33	20	7	4	29
TOTAL BOATS	135	10	26	40	47	65	164	101	9	13	14	13	188	168	849	196	166	153	225
PEOPLE																			
FISHERMEN																			
BOAT	11	7	7	0	18	37	114	45	13	2	13	1	28	15	67	42	12	6	66
BANK	12	3	13	0	0	0	9	0	2	0	18	10	29	47	23	43	25	34	62
(Total)	(23)	(10)	(20)	(0)	(18)	(37)	(123)	(45)	(15)	(2)	(31)	(11)	(57)	(62)	(90)	(85)	(37)	(40)	(128)
BOATERS	9	10	0	0	3	14	5	9	2	20	25	9	107	102	401	46	134	173	175
SKIERS	0	0	0	0	0	0	0	0	0	0	3	4	3	5	10	0	4	19	24
SWIMMERS	0	0	0	0	0	0	0	0	0	0	0	0	5	0	4	1	1	5	30
WADERS	1	0	0	0	0	0	0	0	0	0	3	0	11	6	18	19	15	14	58
(Total Water Contact Sports)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(6)	(4)	(19)	(11)	(32)	(20)	(20)	(38)	(112)
TOTAL PEOPLE	33	20	20	0	18	51	128	54	17	22	62	24	183	175	523	151	191	251	415

Figure 1. RECREATIONAL USE OF SACRAMENTO RIVER
Hamilton City to Rio Vista
September 3–5, 1960

Table 5

BOATING FROM ANDERSON TO BUTTE CITY, 1956-1960

	October 1956	September 1960
Number of Resorts	22 + 1 county park	21 + 4 county parks
Rental Boats	145	91
Private Boats (moored)	485	764
Private Boats (launched)	150	384
Persons Fishing From Boats	1,075 (combined)	1,492
Persons Pleasure Boating		407

Fish and Wildlife

Sacramento River water provides for large numbers of migratory and resident fish and wildlife. The anadromous fish of the river and the migratory waterfowl of the Pacific Flyway are of major economic importance to all the states of the Pacific Coast. These renewable resources are dependent upon both the quantity and quality of river water. Protection of these resources is also dependent upon appropriate control of waste discharges into the river.

An important commercial fishery depends on the king salmon of the Sacramento River. This is an anadromous species which is hatched in upstream reaches, begins its journey to the ocean after a month or two of stream life, attains adulthood in about four years in the ocean, and returns to the river to spawn and die. The estimated contribution of the Sacramento and San Joaquin Basins to the California king salmon fishery from 1948 to 1959 was 5,800,000 pounds retailing at approximately $3,600,000 annually. Morever, king salmon from these basins contribute

an appreciable but unknown amount to the Oregon and Washington commercial fisheries.

An indication of the economic value of California's anadromous sport fisheries is seen in gross annual expenditures of anglers. The California Department of Fish and Game estimated that anglers spent about $26,000,000 in 1953 fishing for king salmon, steelhead, and striped bass in the Sacramento and San Joaquin Basins. Undetermined expenditures were made in connection with fishing for American shad, white catfish, channel catfish, black bass, and panfish. Current expenditures are not known, but they are certainly greater than the 1953 amounts.

Many thousands of acres in the Sacramento Valley provide habitat for wildlife. For example, Colusa, Sutter, and Butte Basins provide wintering areas for five to eight million waterfowl that frequent the Pacific Flyway, a migration path which extends along the western part of North America and funnels through the Central Valley of California. These lands also provide considerable habitat for pheasants.

Sacramento River water is essential to the maintenance of the above fish and wildlife populations, and reservoir releases have been established for this purpose. Minimum fish releases from Shasta Dam provide from 2,300 to 3,900 cfs, depending on the season, during normal years and from 2,000 to 2,800 cfs during critical years. Minimum releases from Folsom Dam assure 500 cfs in the American River during the spawning season and 250 cfs throughout the rest of the year. Other diversions of Sacramento River water through the Delta-Mendota Canal are made in the fall for wild-fowl habitat in the San Joaquin Valley grasslands.

Navigation

The Sacramento River channel is maintained at minimum depths of 10 feet from the Delta to the City of Sacramento and six feet between

Sacramento and Colusa. These depths are provided by maintaining a minimum stream flow of 5,000 cfs at the navigation control point near Wilkins Slough.

An estimated 5,550,000 tons of commercial products, consisting primarily of petroleum products with a lesser, though significant, quantity of farm produce, were shipped through the Sacramento River's navigation system in 1960. There is also a large amount of military shipping.

Under future conditions, the minimum flow at the navigation control point will be 4,000 cfs with an allowable depletion of 1,000 cfs downstream from the control point during the irrigation season.

By 1990, commercial shipping in the Sacramento River area is expected to be about 15,000,000 tons. Military shipments are not included. Petroleum will remain the principal commodity to be shipped.

Waste Disposal

The history and public health benefits of water-borne waste collection and treatment systems are well known. Local physiographic, land-use and economic considerations have often resulted in ultimate disposal of these wastes to watercourses. Accordingly, a major use of the Sacramento River is for the disposal of wastes. The effects of waste disposal on the Sacramento River are discussed in Chapter V. Pertinent data on individual waste collection, treatment, and disposal works are presented on the following pages.

Domestic and Municipal Wastes

Present Discharges to Sacramento River. Quantities of sewage treatment plant effluents discharged directly to the river in 1960 are listed in Table 6 and locations of the discharges are shown on Plate 1.

Discharges from other sewage treatment plants in the Sacramento area reach the river through drains and tributaries.

Table 6

SEWAGE TREATMENT PLANT DISCHARGES TO SACRAMENTO RIVER, 1960

Communities	Treatment Facilities			Design Flow (MGD)	Average Flow (MGD)	Average BOD (ppm)
	Date of Construction	Type of Treatment	Post-chlorination			
Redding	1948	Primary	None	3.75	2.1	139
Red Bluff	1952	Primary	None	0.9	1.1	130
Corning	1949	Primary*	10 ppm	0.4	0.2	---
West Sacramento	1954	Primary	0.5 ppm residual	5.0	2.0	148
Sacramento (main plant)	1954	Primary	Subresidual	54	49.4	151
Sacramento (Meadowview plant)	1958	Primary	None	2.75	0.2	140
Isleton	1956	Primary	0.5 ppm residual	0.65	0.1	70
Rio Vista	1954	Primary	None	0.72	0.2	80

* Land disposal in summer.

The bacteriological quality of the effluents depends upon the degree of postchlorination, while bacterial populations in the river depend upon the chlorination, the dilution afforded by the river, and time of travel. Coliform bacteria concentrations in the discharges vary from a few hundred per 100 ml in highly chlorinated effluents to several tens of millions per 100 ml for unchlorinated effluents. The organic loadings on the river are measured by the amount of oxygen utilized in five days or the biochemical oxygen demand (BOD). BOD concentrations of the discharges vary throughout the day at the various plants. Seasonal discharges

of industrial wastes from food processing plants are also reflected in the BOD's.

Present Discharges to Tributary Streams. Although there are a number of sewage treatment plants which discharge to various tributary streams, the locations and flows of only those plants serving communities and industries north and east of Sacramento are of significance to the Sacramento River. These discharges eventually reach the Sacramento River by either the Natomas East Main Drain or the American River. Both enter the east side of the Sacramento River at river mile 60.4 within a few hundred yards of each other, immediately upstream from the City of Sacramento water intake.

Future Discharges. The Redding Sewage Treatment Plant has sufficient capacity to treat the expected increase inflows from the city for the near future. When present facilities become inadequate, it is proposed in the City of Redding's master plan that new facilities will be constructed south of town.

The sewage treatment plant at Red Bluff is overloaded by 15 to 20 percent during much of the year. The city is presently investigating the possibility of obtaining another site for sewage treatment facilities and may revert to land disposal of the effluent from the new treatment plant.

The Sacramento area is undergoing a rapid population expansion and a number of changes and additions to the present sewage treatment facilities are proposed. A new secondary sewage treatment plant has been proposed to serve the area north of Sacramento on the east side of the Sacramento River known as the Natomas Sewer Maintenance District. The plant will have a design capacity of 4.5 MGD and will eventually discharge

into the East Drainage Canal of the Natomas Main Drain and reach the Sacramento River at river mile 61.5.

A new sewage treatment plant under county supervision and operation is under construction to serve the area northeast of Sacramento along the American River. The initial design capacity of the secondary treatment plant will be 9 MGD. The effluent from the plant will enter the American River approximately 12 miles above its confluence with the Sacramento River.

The Southeast Sanitation District plant is presently under construction southeast of the City of Sacramento which will treat the sewage from new subdivisions in county areas. The plant will provide secondary treatment with an initial design capacity of 8 MGD and an ultimate capacity of 48 MGD. The effluent will enter the Sacramento River at mile 46 which is approximately 14 miles below Sacramento.

No plans have been made as yet by the City of Sacramento for expansion or modification of the Sacramento main plant. The Meadowview Sewage Treatment Plant is presently operating far below its design capacity.

The sewage treatment plant for West Sacramento has undergone additions and modifications which will enable it to handle sewage from the West Sacramento area without further expansion for a number of years.

The present sewage treatment plants at Isleton, and Rio Vista have sufficient capacity to treat any expected increase in wastes from the communities in the forseeable future. Installation of disinfection facilities at the City of Rio Vista Sewage Treatment Plant has been recommended by the State Department of Public Health.

Industrial Wastes

The two significant industrial waste discharges to the Sacramento River are from a wood products plant near Red Bluff and a sugar beet processing plant at Clarksburg. Minor discharges include several log pond overflows in the Redding - Red Bluff area (one sizeable flow, 1 MGD, reaches the Sacramento River via Anderson Creek), an intermittent discharge of diluted battery acid near Sacramento, cooling water from a food storage plant at Hood, and wastes from a mushroom plant near Locke. In the past, seasonal occurrences of tastes and odors in the Sacramento water supply are believed to be associated with an industrial discharge from a military installation which eventually reaches the Sacramento River a short distance upstream from the water intake.

Diamond National Corporation. The Diamond National Corporation plant located two miles south of Red Bluff produces molded paper products such as plates and trays. About 0.5 MGD of waste is produced which contains sulfur compounds, silica, and wood pulp. Another 1.5 MGD of waste consists of supernatant containing wood fiber from molded pulp processing operations. Wastes from both processes are settled with alum and treated with lime to control the pH and discharged to settling and leaching ponds located beside Redbank Creek. Redbank Creek also receives 1.5 MGD from a log pond. BOD's in the creek vary from 2 to 90 ppm.

American Crystal Sugar Company. This company processes sugar beets at a plant in Clarksburg. In 1960, the operation ran from August 9 to December 1. Flows generally vary from 3 to 4 MGD and BOD's range from 240 to 550 ppm.

Agricultural Drainage

Most of the agricultural return water is discharged to the river in the 20-mile reach above the Feather River (mile 79.9). Table 7 lists major annual discharges from 1950 to 1959.

Table 7

DISCHARGES FROM IRRIGATION DRAINS TO THE SACRAMENTO RIVER, 1950-59

Drain (river mile)	Discharge (1000 acre-feet)									
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Butte Slough (138.9)	228	168	104	181	205	180	141	122	83	128
Reclamation District 70 (124.2)	16	18	33	31	36	24	34	15	36	21
Reclamation District 108 (100.1)	121	159	172	141	167	126	132	93	151	111
Reclamation District 787 (93.6)	6	9	19	22	19	11	27	13	22	16
Colusa Basin Drain (90.2)	261	310	225	305	271	355	326	353	236	356
Sacramento Slough (80.8)	338	335	200	180	345	445	276	246	370	232
Natomas Cross Canal (79.1)	171	*	214	81	83	107	152	48	12	4
Reclamation District 1000 (61.5 - 75.5)	43	38	77	45	46	51	65	17	82	9
TOTAL	1,184	1,037	1,043	987	1,172	1,298	1,152	907	992	877

* No record.

Table 7 indicates that the total irrigation waste discharged from the eight drains is over 34 percent of the total amount of water diverted for irrigation between Sacramento and Redding. Since the overall Sacramento Valley irrigation water service area efficiency is

approximately 60 percent, practically all of the unused applied irrigation water returns to the river by the drains listed in the table.

Salinity Repulsion

The lower reach of the Sacramento River is subject to salinity intrusion from the ocean. The extent of this incursion is governed by the height of the tidal rise and the flow in the river.

Natural fresh water outflow from the Central Valley is inadequate to repel salinity during summer months. The maximum recorded extent of salinity incursion occurred in September 1931, when ocean salts reached 35 miles upstream in the Sacramento River.

The control of sea-water invasion is presently effected by repelling the saline water with fresh water released from upstream reservoirs. Since operations of the Central Valley Project began in 1949, intrusion of sea water into Sacramento River has extended only to mile 7.0. Without such operational releases, in 1955 saline water would have intruded about 90 percent of the Delta channels.

Reservoir releases for salinity control are coordinated with releases for navigation, hydroelectric power generation, and other beneficial uses of the water.

CHAPTER V. WATER QUALITY

The Sacramento River responds to heat and cold, light and dark, geographical and geological features, and activities of man in much the same manner as a domestic animal. Like a domestic animal, it provides man with both practical and intangible benefits, and it can be abused.

The behavior of the river is determined by its many physical, chemical, and biological characteristics. Some of the constituents are conservative; that is, once they are added, they stay. Common salt, for example, added by leaching of irrigated fields or by municipal use of the water remains in the water thereafter. Concentrations are increased by evaporation from water surface or through plants. With respect to dissolved conservative constituents, the river is the sum of its parts.

Nonconservative constituents in a stream are those which are subject to change by biological processes. Photosynthesis by floating and attached plants adds food and oxygen to the water. This food, together with that introduced by tributary flows and waste discharges, is used by animals and bacteria. Wherever there is food, there is feasting and with this feasting, there is consumption of oxygen by respiration. The amount of oxygen dissolved in the water decreases accordingly. Under extreme conditions, the dissolved oxygen is utilized more rapidly than it can be supplied by the atmosphere and by photosynthesis combined, and the stream becomes septic. In addition to oxygen, nonconservative constituents include carbon, nitrogen, and phosphorus, and, to lesser extent, silica and trace constituents, all of which are constantly shifting between organic and inorganic forms.

The various beneficial uses discussed in the preceding chapter, some of which are competing, have different water quality requirements.

These requirements and the effect of these uses on the river are presented in the following pages.

Water Quality Criteria

Criteria utilized in evaluation of the quality of water of the Sacramento River are presented in two categories: (1) general criteria which are applicable to broad classifications of uses and not associated with any particular source of water supply, and (2) specific criteria related directly to the water of the Sacramento River.

General Criteria

These criteria were used as guides in determining the suitability of a water supply with respect to the following broad categories of uses: domestic and municipal water supply, industrial water supply, irrigation water supply, and preservation of fish and wildlife.

Domestic and Municipal Water Supply. Chapter 7 of the California Health and Safety Code contains laws and standards relating to domestic water supply. Section 4010.5 of this code refers to the drinking water standards promulgated by the United States Public Health Service for water used on interstate carriers. These criteria have been adopted by the State of California. They are set forth in detail in United States Public Health Report, Volume 61, No. 11, March 15, 1946, reissued in March 1956.

According to Section 4.2 of the above-named report, chemical substances in drinking water supplies, either natural or treated, should conform to the limitations presented in Table 8.

Table 8

LIMITING CONCENTRATIONS OF CHEMICAL CONSTITUENTS FOR DRINKING WATER

United States Public Health Service Drinking Water Standards, 1946

Constituents	Parts Per Million
Mandatory	
Fluoride (F)	1.5
Lead (Pb)	0.1
Selenium (Se)	0.05
Hexavalent chromium (Cr^{+6})	0.05
Arsenic (As)	0.05
Nonmandatory but Recommended Values	
Iron (Fe) and manganese (Mn) together	0.3
Magnesium (Mg)	125
Chloride (Cl)	250
Sulfate (SO_4)	250
Copper (Cu)	3.0
Zinc (Zn)	15
Phenolic compounds in terms of phenol	0.001
Total solids - desirable	500
- permitted	1,000

The 1946 standards also states that turbidity shall not exceed 10 ppm (silica scale), that color shall not exceed 20 (platinum-cobalt scale), and that the water shall have no objectionable taste or odor.

In 1962, the Public Health Service adopted a revised set of drinking water standards. These have not yet been adopted by the State of California. They are presented in Chapter IV, Appendix C.

Interim standards for certain mineral constituents have recently been adopted by the California State Board of Public Health. Based on these standards, temporary permits may be issued for drinking water supplies failing to meet the United States Public Health Service Drinking

Water Standards, provided the mineral constituents in Table 9 are not exceeded.

Table 9

UPPER LIMITS OF TOTAL SOLIDS AND SELECTED MINERALS IN DRINKING WATER AS DELIVERED TO THE CONSUMER

California State Board of Public Health

	Permit*	Temporary Permit
Total solids	500 (1000)	1,500 ppm
Sulfates (SO_4)	250 (500)	600 ppm
Chlorides (Cl)	250 (500)	600 ppm
Magnesium (Mg)	125 (125)	150 ppm

* Numbers in parentheses are maximum permissible, to be used only where no other more suitable waters are available in sufficient quantity for use in the systems.

The California State Board of Health has defined the maximum safe amounts of fluoride ion in drinking water in relation to mean annual temperature.

Mean annual temperature in °F	Mean monthly maximum fluoride ion concentration in ppm
50	1.5
60	1.0
70 - above	0.7

The relationship of infant methemoglobinemia (a reduction of oxygen content in the blood, constituting a form of asphyxia) to nitrates in the water supply has led to limitation of nitrates in drinking water. The California State Department of Public Health has recommended a tentative limit of 10 ppm nitrogen (44 ppm nitrates) for domestic waters. Water containing higher concentrations of nitrates may be considered to be of questionable quality for domestic and municipal use.

Limits may be established for other organic or mineral substance if, in the judgment of state or local health authorities, their presence in water renders it hazardous.*

An additional factor with which water users are concerned is hardness. Hardness is due principally to calcium and magnesium salts and is generally evidenced by inability to develop suds when using soap. The United States Geological Survey considers the four classes of hardness listed in Table 10 (44).

Table 10

HARDNESS CLASSIFICATION OF WATERS
U. S. Geological Survey

Range of hardness in ppm	Relative classification
0 - 60	Soft
61 - 120	Moderately hard
121 - 200	Hard
Above 200	Usually requires softening

Criteria for Irrigation Water. Criteria for mineral quality of water have been developed by the Regional Salinity Laboratories of the United States Department of Agriculture in cooperation with the University of California.

Because of the diverse climatological conditions, crops, soils, and irrigation practices in California, criteria which may be set up to evaluate the suitability of water for irrigation use must necessarily be of general nature, and judgement must be used in their application to individual cases. Suggested limiting values for total dissolved solids, chloride concentration, percent sodium and boron concentration for three general classes of irrigation waters are shown in Table 11.

* A detailed discussion of water quality and the public health is presented in the addendum to this bulletin on page 90.

Table 11

QUALITATIVE CLASSIFICATION OF IRRIGATION WATERS

Chemical properties	Class 1 Excellent to good (Suitable for most plants under any conditions of soil and climate)	Class 2 Good to injurious (Possibly harmful for some crops under certain soil conditions)	Class 3 Injurious to unsatisfactory (Harmful to most crops and unsatisfactory for all but the most tolerant)
Total dissolved solids:			
In ppm	Less than 700	700 - 2,000	More than 2,000
In conductance micromhos at 25°C	Less than 1,000	1,000 - 3,000	More than 3,000
Chloride ion concentration:			
In milliequivalents per liter	Less than 5	5 - 10	More than 10
In ppm	Less than 175	175 - 350	More than 350
Sodium in percent of base constituents	Less than 60	60 - 75	More than 75
Boron in ppm	Less than 0.5	0.5 - 2.0	More than 2.0

Industrial Water Supply. Water quality criteria for industrial waters are as varied and diversified as industry itself. Food processing, beverage production, pulp and paper manufacturing, and textile industries have exacting requirements, while poor quality waters can be used for some cooling or metallurgical operations. In general, where a water supply meets drinking water standards, it is satisfactory for industrial use, either directly or following a limited amount of polishing treatment or softening by the industry.

Preservation and Protection of Fish and Wildlife. A healthy and diversified aquatic population is indicative of good water quality

conditions which in turn permit optimum beneficial uses of the water. For such a population to exist, the environment must be suitable for both the fish and the food-chain organisms.

Many mineral and organic substances, even in low concentrations, are harmful to fish and aquatic life. Insecticides, herbicides, ether-soluble materials, and salts of heavy metals are of particular concern. It may be noted that although the drinking water standards presented in Table 8 permit as much as 3.0 and 15 ppm of copper and zinc, respectively, such levels are highly toxic to fish.

Tolerance to temperature extremes varies widely between fish species. In general, cold water fish are found in waters of from 32° to 65°F; warm water fish require temperatures between 45° and 85°F. The maximum temperature for successful salmon spawning is 58°F. Rapid changes in water temperature may result in fish kills.

The minimum requirements for dissolved oxygen concentrations vary with the location and season. In general, 5 ppm is satisfactory for migrating fish. However, anadromous fish require at least 7 ppm dissolved oxygen in spawning areas and, under some conditions, 9 ppm is needed.

It has been found that fish can thrive between pH limits of 6.5 and 8.5.

The combined effect of many chemical or physical characteristics are not the simple sum of the specific effects. For example, while the hardness of the water does not of itself affect fish, some insecticides are more toxic in soft water and others are more toxic in hard water (Chapter II, Appendix C). These problems of synergistic and antagonistic effects extend through a wide range of materials and conditions. Frequently, predictions of the effects of a particular waste discharge are made from biological studies in similar waters receiving similar wastes. In many

cases, these requirements for similarity may not be met and laboratory bioassays are necessary.

Specific Criteria

Specific criteria which are related to water quality of the Sacramento River are included in (1) a policy statement adopted by the Central Valley Regional Water Pollution Control Board, (2) recommendations by a board of consultants on water quality, and (3) a contract between the California State Department of Water Resources and the Metropolitan Water District of Southern California.

Policy of the Central Valley Regional Water Pollution Control Board (No. 5). In September 1954, the board adopted Resolution No. 54-35 to provide guidance in preparing quality requirements for wastes to be discharged into the Sacramento River. Relevant sections of this resolution are quoted as follows:

> "RESOLVED, that as an initial policy the waters of the Sacramento River at the Division of Water Resources sampling station (Station No. 15) at M Street Bridge near the City of Sacramento:
>
> 1. Shall not have a sulphate concentration in excess of 4 ppm over the sulphate concentration present in the river at the same sampling station. Maximum observed to date 40 ppm.
> 2. Shall not have a chloride concentration in excess of 4 ppm over the present chloride concentration at the same sampling station. Maximum observed to date 20 ppm.
> 3. Shall not have a sodium concentration in excess of 4 ppm over the present sodium concentration at the same sampling station. Maximum observed to date 25 ppm.
> 4. Shall not have a hardness concentration in excess of 4 ppm over the present. Maximum observed to date 92 ppm.

5. Shall not have a total solids concentration in excess of 25 ppm over present. Maximum observed to date 176 ppm; and be it

RESOLVED further, That

6. The Sacramento River at no point shall have a dissolved oxygen concentration of less than 85 percent saturation.

7. The waters of the Sacramento River at all points shall be bacteriologically safe for its present use.

8. The waters of the Sacramento River shall be free of grease slicks and floating solids of sewage or waste origin.

9. The Sacramento River shall have no substances discharged to it of such character or quantity as to be injurious to humans, plant, animal, fish or aquatic life.

10. The Sacramento River shall have no substances discharged to it of such character or quantity as to be injurious for irrigation use.

11. The Sacramento River shall not have sludge of sewage or waste origin deposited either on its bottom or banks.

12. The Sacramento River shall receive no waste discharges which will cause objectionable discoloration.

13. Waste discharges to the river shall not raise the temperature of the Sacramento River more than 0.5°F at any point.

14. Waste discharges shall not cause the pH of the river to fall below 6.5 nor rise above 8.5 at any point except that no more than 10 percent of the samples shall be less than 7.0 and no more than 10 percent of the samples shall be more than 8.0.

15. The Sacramento River shall have no substances in it of such character or quantity as to be capable of causing detectable tastes or odors in a domestic water supply after conventional and practical treatment."

<u>Recommendations of Board of Consultants</u>. A board of consultants was retained by the Department of Water Resources to recommend water quality criteria for water for export at points of diversion at the southern boundary of the Sacramento-San Joaquin Delta under the ultimate pattern of water transfer and use proposed in The California Water Plan (26). The

1955 recommendations of this board listed in Table 12 were adopted by the Department of Water Resources as the quality objectives to be met at points of diversion from the Delta for water to be exported to the major areas of deficiency.

Table 12

WATER QUALITY LIMITS FOR WATER FOR EXPORT AT POINTS OF DIVERSION AT SOUTHERN BOUNDARY OF SACRAMENTO-SAN JOAQUIN DELTA

Recommended by Board of Consultants on Water Quality
June 1955

Item	Limit
Total Dissolved Solids	400 ppm
Electrical Conductance (EC x 10^6 at 25°C)	600
Hardness as $CaCO_3$	160 ppm
Sodium Percentage	50
Sulfate	100 ppm
Chloride	100 ppm
Fluoride	1.0 ppm
Boron	0.5 ppm
pH	7.0 - 8.5
Color	10 ppm
Other constituents as to which the U. S. Public Health Service has or may establish mandatory or recommended standards for drinking water	USPHS Limits

Contract Between the State of California and the Metropolitan Water District. In November 1960, the Department of Water Resources entered into a contract with the Metropolitan Water District for transport of surface waters to southern California for use by the district. The contract sets forth quality objectives to be met by the State at points of delivery to the district. These objectives are listed in Table 13 as a guide for evaluation of the quality of the Sacramento River.

"It shall be the objective of the State and the State shall take all reasonable measures to make available, at all delivery structures for delivery of project water to the District, project water of such quality that the following constituents do not exceed the concentrations stated as follows:

Table 13

WATER QUALITY OBJECTIVES FOR
THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

Constituent	Unit	Monthly Average	Average for any 10-Year Period	Maximum
Total Dissolved Solids	ppm.	440	220	-
Total Hardness	ppm.	180	110	-
Chlorides	ppm.	110	55	-
Sulfates	ppm.	110	20	-
Sodium Percentage	%	50	40	-
Fluoride	ppm.	-	-	1.5
Lead	ppm.	-	-	0.1
Selenium	ppm.	-	-	0.05
Hexavalent Chromium	ppm.	-	-	0.05
Arsenic	ppm.	-	-	0.05
Iron and Manganese together	ppm.	-	-	0.3
Magnesium	ppm.	-	-	125.
Copper	ppm.	-	-	3.0
Zinc	ppm.	-	-	15.
Phenol	ppm.	-	-	0.001

Subsequent contracts between the Department of Water Resources and local agencies have included water quality objectives consistent with those in Table 13.

Physical and Chemical Characteristics of Sacramento River Water

Temperature

Water temperatures at Keswick generally vary between 50 and 55°F. During winter months, temperatures decrease as the water moves downstream. For the rest of the year, temperatures rise to between about 60°F and 75°F above Sacramento. After being cooled a few degrees by inflows

from the American River, temperatures remain essentially constant except for a local seasonal increase below Walnut Grove where current reversals due to tides are important.

pH

The Sacramento River is slightly alkaline with a median pH of 7.3 from Keswick to Rio Vista. Tributary streams have similar pH values while irrigation returns are somewhat more alkaline. Spring Creek is strongly acid because of mine wastes; however, this discharge is quickly neutralized so that no effect on the river was observed.

Suspended Solids, Turbidity, and Color

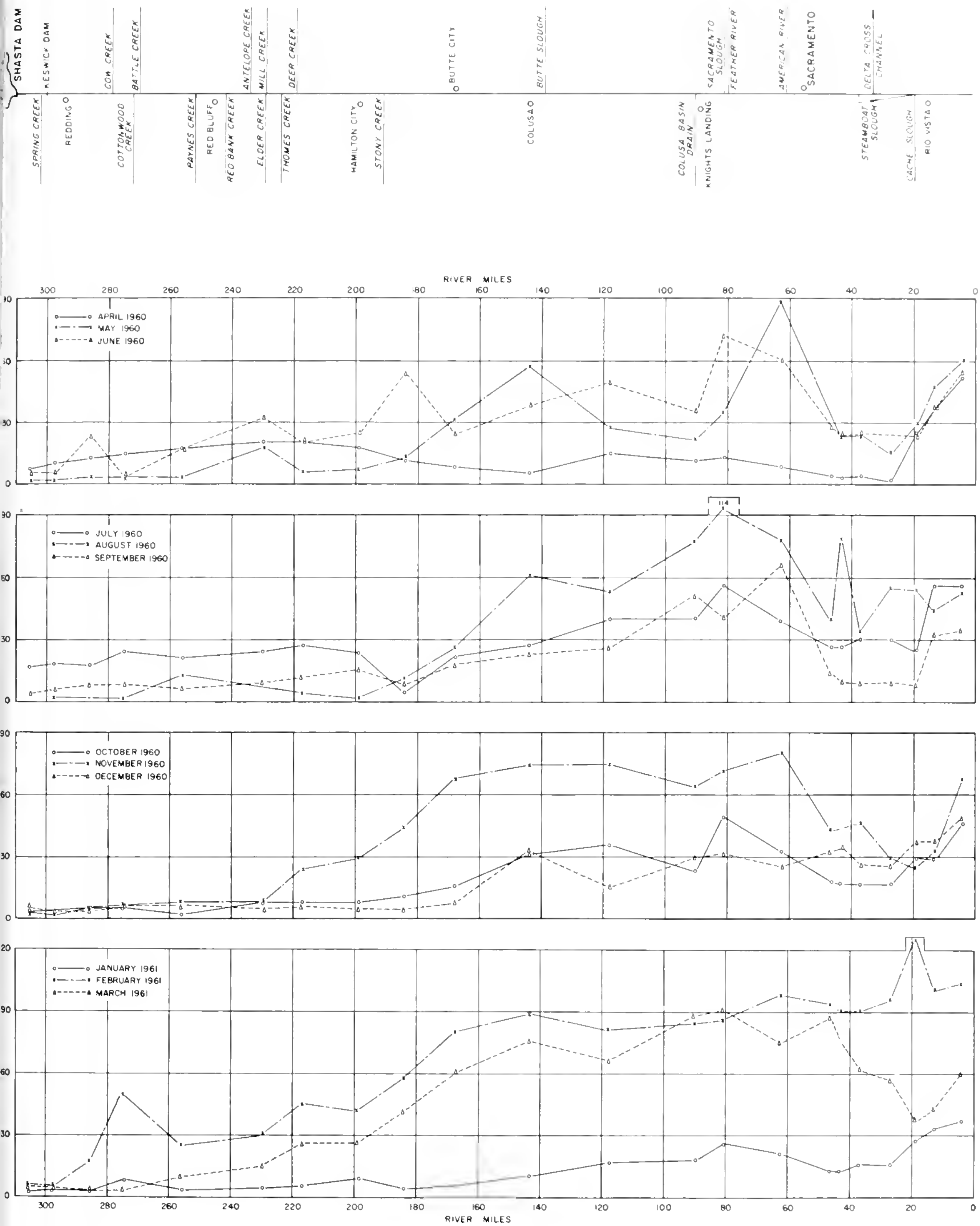
Concentrations of suspended solids, turbidity, and color increase with distance from Keswick. Seasonal increases are due to unregulated tributary flows, to irrigation returns, and to algae and other plankton.

Figure 2 shows suspended solids concentrations observed in 1960-61. Unpublished records of the U. S. Geological Survey reveal approximately the same concentrations as those shown in the figure during low flow periods; however, during winter storms, much higher average values are reported.

The 1946 Public Health Service drinking water standards set a limit of 10 ppm on turbidity and 20 color units. Although turbidities and color are usually within these limits, provision for their removal should be made in domestic water systems.

Total Dissolved Solids

Concentrations of total dissolved solids may be determined by weighing the residue of evaporation or by summation of the concentrations of individual constituents. The electrical conductivity of water is directly proportional to the amount of dissolved minerals and can be measured continuously; this is reported as specific conductance in micromhos.



SACRAMENTO RIVER WATER POLLUTION SURVEY

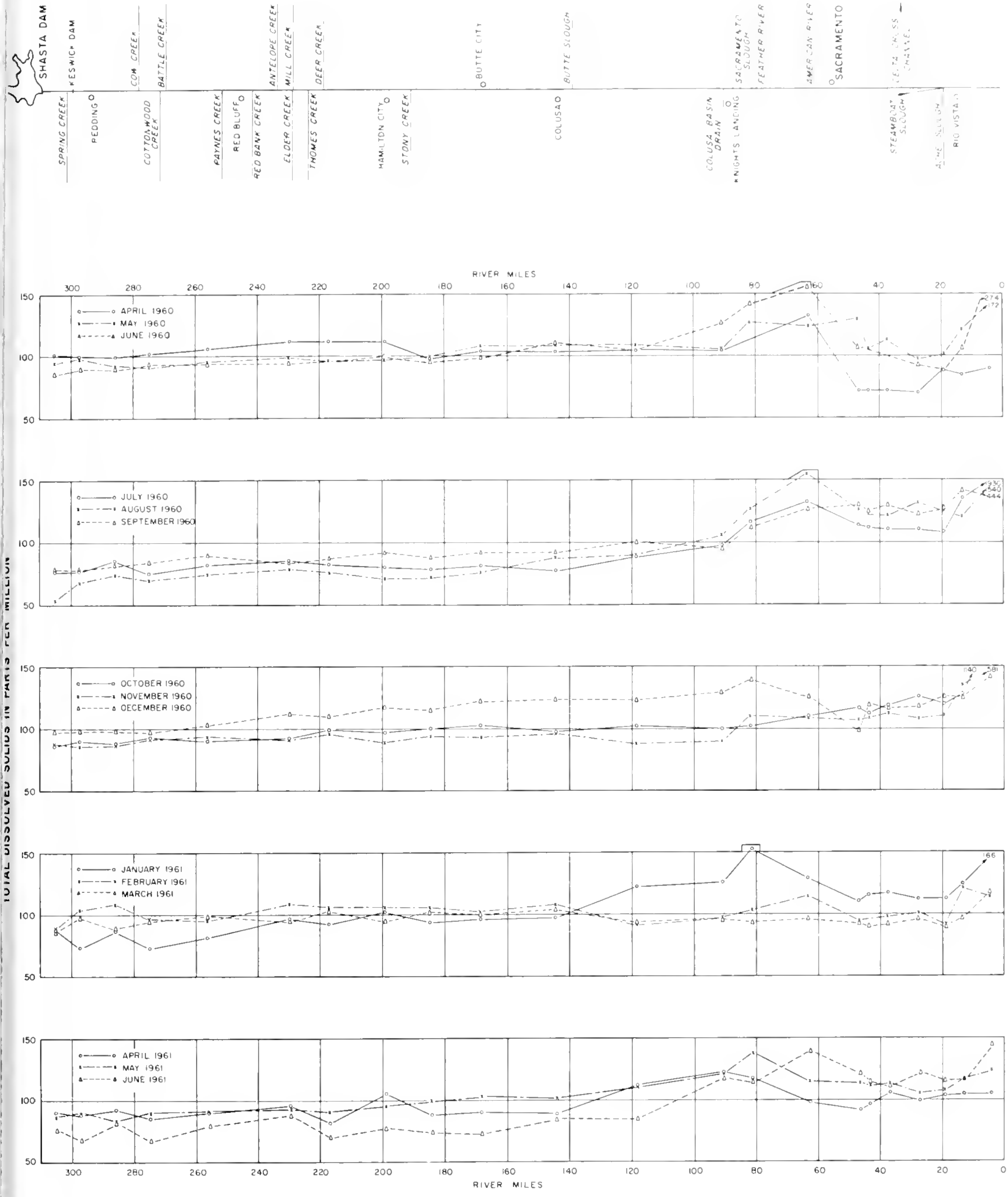
Figure 2. SUSPENDED SOLIDS — SACRAMENTO RIVER 1960—1961

Figures 3 and 4 show how total dissolved solids and specific conductance, respectively, varied throughout the river during the period of investigation. Generally, the concentration of total dissolved solids in ppm is about six-tenths of the specific conductance in micromhos. The figures show that during months of spring snowmelt, solids concentrations in the river tend to be reduced by tributary flows. During the rest of the year, concentrations increased due to irrigation return flows. The maximum increase occurred in September when concentrations approximately doubled between Keswick and Bryte. Solids concentrations were reduced by Feather and American River flows and were sharply increased in the lowest reaches by tidal waters.

Continuous conductivity recorders installed at locations shown on Plate 1 showed that intermittent discharges of irrigation return waters, particularly from the pumping plant of Reclamation District No. 108 (mile 100.1), could be traced down the river. The record clearly showed that monthly and daily sampling downstream had historically missed R. D. 108 discharges. These discharges were made at night in order to take advantage of off-peak power rates and could be traced downstream to Isleton (mile 18.8), the most distant recorder.

Hardness

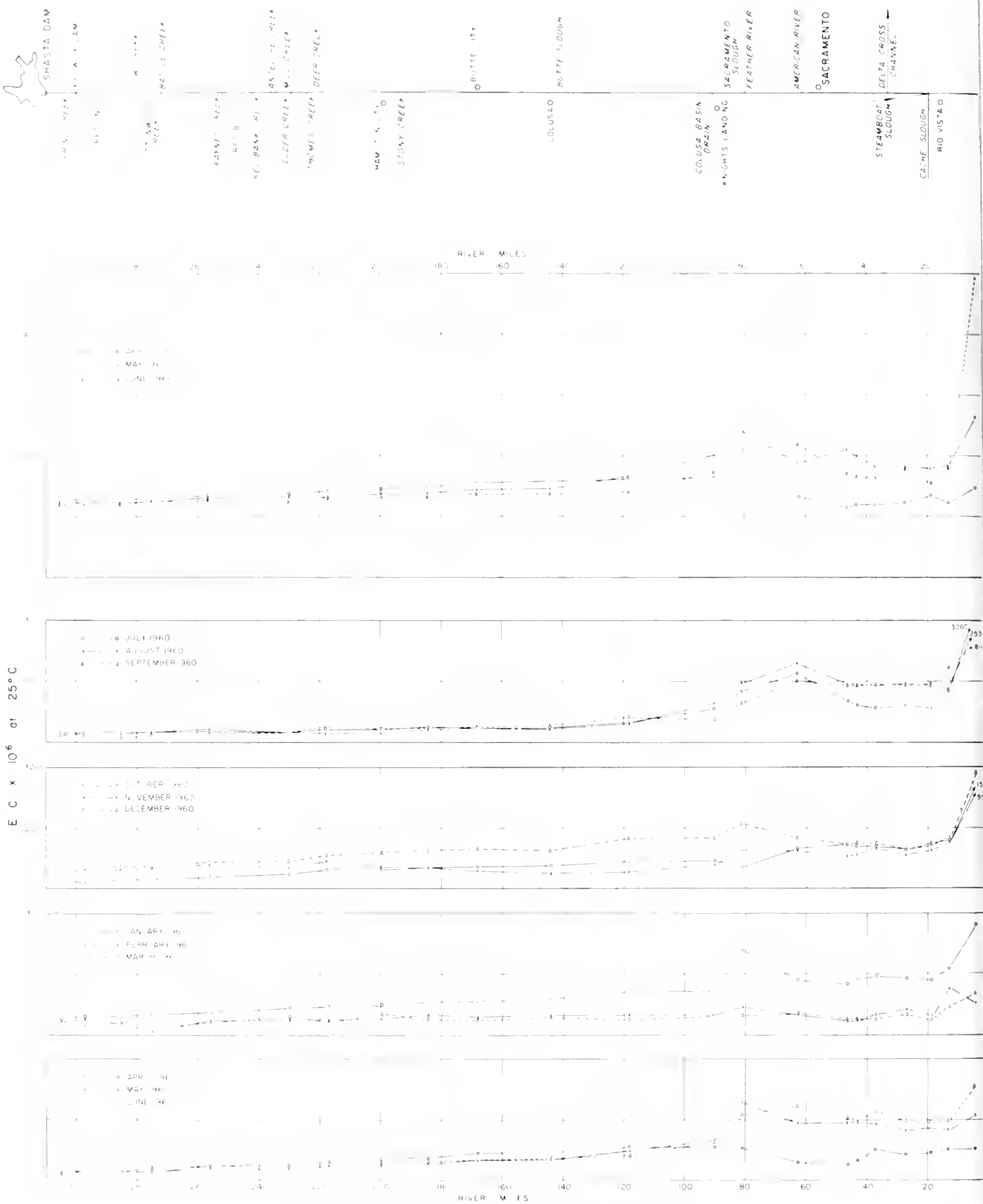
Water in the Sacramento River is very soft in the upper reach. Hardness is added by irrigation returns, but the river is still generally soft at Sacramento. Table 14 summarizes observations of hardness in the river and tributaries during the survey period.



SACRAMENTO RIVER WATER POLLUTION SURVEY

Figure 3. TOTAL DISSOLVED SOLIDS — SACRAMENTO RIVER

1960–1961



SACRAMENTO RIVER WATER POLLUTION SURVEY

Figure 4. SPECIFIC CONDUCTANCE – SACRAMENTO RIVER 1960–1961

Table 14

HARDNESS IN SACRAMENTO RIVER AND TRIBUTARIES, 1960-61

Station	Maximum ppm	Minimum ppm	Median ppm
Sacramento River			
Redding (297.7)	49	42	44
Hamilton City (199.6)	58	46	48
Snodgrass Slough (37.2)	67	44	59
Tributaries			
Butte Slough	163	86	128
Colusa Basin Drain	296	100	136
Sacramento Slough	281	132	174
Feather River	61	31	49
American River	30	18	24

Corrosion Potential

The Langelier index of a water supply is determined from the pH, alkalinity, and calcium in the water. A negative index indicates that the water is undersaturated with calcium carbonate and may corrode iron pipes. A positive index indicates an excess of calcium carbonate which is likely to form scale on pipes and fixtures. Table 15 lists typical values of the Langelier index for Sacramento River water.

Table 15

LANGELIER SATURATION INDEX OF SACRAMENTO RIVER WATER

Location	Mile	Index
Redding	293.7	-1.9
Red Bluff	244.1	-1.8
Hamilton City	199.6	-1.6
Butte City	168.2	-1.5
Knights Landing	90.5	-1.4
Bryte	62.6	-1.6
Freeport	46.4	-1.8
Rio Vista	12.8	-1.7
Mayberry Slough	4.0	-1.6

Corrosion problems may be expected in cold or hot waters with indices more negative than -0.5 and 0.0, respectively, and the corrosion tendency of Sacramento River water is apparent from Table 15. The greatest corrosion potentials occur just below Shasta Dam and below the mouths of the Feather and American Rivers.

Major Constituents

Concentrations of major constituents in the Sacramento River during 1960-61 varied in the same degree and from the same causes as total solids.

During the months of August through October 1960, when irrigation return flows were most significant, average concentrations at Freeport (mile 46.4) were: calcium - 14.2 ppm, magnesium - 8.1 ppm, sodium - 14.5 ppm, potassium - 1.3 ppm, bicarbonate - 90.4 ppm, sulfate - 10.1 ppm, and chloride - 10.0 ppm. Percent sodium was about 30. These concentrations are well within the limits for beneficial uses stated previously.

Minor Constituents

Within the river, concentrations of minor constituents were less than various limiting criteria except for occasional slight excesses of iron and manganese in the Redding area during storm periods. Fluoride concentrations varied randomly between 0.0 and 0.3 ppm. Average concentrations of silica decreased from about 24 ppm above Redding (mile 297.7) to 20 ppm at Snodgrass Slough (mile 37.2). Boron averaged about 0.1 ppm throughout the river.

Phosphate was generally 0.1 ppm above Sacramento and from 0.2 to 0.4 ppm below Sacramento, reflecting the use of detergents.

Total nitrogen in the river was generally between 0.1 and 0.4 ppm above Sacramento and 0.35 to 0.55 ppm below Sacramento. Inorganic nitrogen as ammonium, nitrite, and nitrate was relatively constant while organic nitrogen approximately followed plankton concentrations.

Heavy metals in the river were found only in very low concentrations. In the upper reach, where acid mine wastes from Spring Creek have long been suspected of contributing to fish kills, somewhat higher concentrations were observed as summarized in Table 16.

Table 16

HEAVY METALS IN THE UPPER SACRAMENTO RIVER AND IN SPRING CREEK
(in ppm)

Constituent	Sacramento River*			Spring Creek	
	Maximum (1952-60)	Maximum (1960-61)	Median (1960-61)	Maximum (1960-61)	Median (1960-61)
Iron (Total)	----	----	----	438	---
Iron (Dissolved)	0.34	0.80	0.05	308	116
Aluminum	0.31	0.49	0.0	133	33
Arsenic	0.01	0.04	0.00	0.32	0.00
Chromium (Hexavalent)	0.1	0.1	0.00	0.00	---
Chromium (Total)	----	----	----	0.04	---
Copper	0.07	0.13	0.00	15	3.4
Lead	0.09	0.03	0.00	0.66	0.03
Manganese	0.01	0.29	0.00	2.6	0.79
Zinc	0.09	0.10	0.2	136	26

* Redding (mile 293.7) to Bend (mile 256.3)

Concentrations of heavy metals in the river are primarily controlled by the quality of influents to Shasta Reservoir. The effects of Spring Creek, although they are small, extend for at least 46 miles.

Large quantities of heavy metals are typically discharged from Spring Creek during the first rains of the season when minimum flows are being released from Shasta Dam (1). A dam has been constructed by the U. S. Bureau of Reclamation on the creek about one-half mile from the mouth. When filled, in 1962-63, Spring Creek Reservoir will hold 6,500 acre-feet of water which can be released at rates which will provide adequate dilution by flows in the Sacramento River.

Analyses for detergents as alkylbenzensulfonate (ABS) in waste discharges to the river are summarized in Table 17.

Table 17

CONCENTRATIONS OF ABS IN WASTE DISCHARGES TO SACRAMENTO RIVER, 1960-61

Waste Discharge	No. of Analyses	Median (ppm)	Range (ppm)
Redding Sewage Treatment Plant	33	5	1.7 - 8.9
Red Bluff Sewage Treatment Plant	33	5.4	2.0 - 8.8
West Sacramento Sewage Treatment Plant	36	8.2	4.8 - 15
Sacramento Sewage Treatment Plant	16	4.0	2.0 - 8.0
Meadowview Sewage Treatment Plant	4	14.0	10 - 24
Isleton Sewage Treatment Plant	19	4.8	0.2 - 5.9
Rio Vista Sewage Treatment Plant	21	6.1	0.1 - 14.0
American Crystal Sugar Company	16	0.2	0.1 - 0.6

ABS concentrations in the river were determined throughout the year on the monthly program and during the first upper reach and first and second lower reach intensive sampling programs.

One-tenth ppm ABS was found in the river downstream from the Redding Sewage Treatment Plant discharge about six percent of the time. Downstream from the Sacramento Sewage Treatment Plant (mile 54.1L), 0.1 ppm occurred about half the time at Freeport (mile 46.4) and about one fifth the time at Rio Vista (mile 12.5). Detergent was reported about 65 percent of the time at Mayberry Slough (mile 4.0) where concentrations of 0.3 ppm were reported on five occasions, but the lack of significant sources in this area suggest that there was some interference with the test.

Periodic analyses of Sacramento River and drainage waters were made by the carbon adsorption method. Plate 1 shows the locations where from 3,000 to 5,000 gallons of water were passed through a carbon filter. The adsorbed organic material was subsequently extracted with alcohol or chloroform, and infra-red spectrograms were made of the extracts. The spectrograms are on file at the Berkeley laboratories of the State

Department of Public Health for future references. The concentrations of weedicides in irrigation drainage waters obtained in this manner have been presented in Chapter IV.

The analyses of river samples revealed that the average total extractable material increased from 114 parts per billion at Keswick Dam to 350 parts per billion at Walnut Grove. The major increase of approximately 170 parts per billion, took place between Sacramento and Walnut Grove.

The average chloroform extractable material increased from 35 parts per billion to 100 parts per billion from Keswick Dam to Walnut Grove. The maximum value at Walnut Grove, 120 parts per billion, is below the value of 200 parts per billion which has been tentatively associated with the presence of tastes and odors in water and which has been specified in the 1961 U. S. Public Health Service drinking water standards (Chapter IV, Appendix C).

The average alcohol extractable material increased from 83 to 250 parts per billion over the same area.

The best general use of the data will lie in the future when the present results can be compared with later analyses.

Direct analyses for phenols and ether solubles showed that these materials were generally absent from the river.

Occurrences of taste and odor which have been observed in the Sacramento water system which occur early in the rainy season are believed to be due to the flushing of creeks that receive industrial wastes and which discharge to the river immediately upstream from the water intake. Threshold odors of Sacramento River water during the present investigation averaged about one unit just below Shasta Dam and increased to about

four units at Freeport. The longitudinal and seasonal variations in odor corresponded closely to algae concentrations in the river.

Radioactivity

Radioactivity in Sacramento River water has been determined semiannually since 1952. No additional radiological sampling was done during the 1960-61 survey period since background radiation has always been small, there are no nuclear reactors on the water shed, and atmospheric fallout was low. Maximum radioactivity in Sacramento River waters for the period of record is listed in Table 18:

Table 18

RADIOLOGICAL ASSAYS OF SACRAMENTO RIVER WATER, 1952-60

Station	Maximum Radioactivity in micromicrocuries per liter			
	Dissolved		Suspended	
	Alpha	Beta	Alpha	Beta
Keswick	10.8 ± 5.4	13.8 ± 6.4	0.9 ± 0.8	24.9 ± 6.9
Redding	6.5 ± 4.6	12.1 ± 7.4	6.8 ± 3.5	9.7 ± 5.8
Hamilton City	9.9 ± 4.1	12.0 ± 9.4	13.7 ± 5.0	14.1 ± 7.9
Knights Landing	12.5 ± 3.7	-	7.9 ± 5.0	14.8 ± 7.4
Sacramento	6.8 ± 3.7	6.5 ± 5.2	13.0 ± 4.0	9.2 ± 7.3
Rio Vista	5.7 ± 4.7	20.2 ± 9.4	11.4 ± 4.5	8.8 ± 7.4

The reported levels of radiation are well below any limits that have been proposed for domestic water supply. There is no evidence that any of the radioisotopes being used by the licensees of the Atomic Energy Commission located throughout the watershed are in any way reaching the river in measurable quantities.

Bacteriological Quality

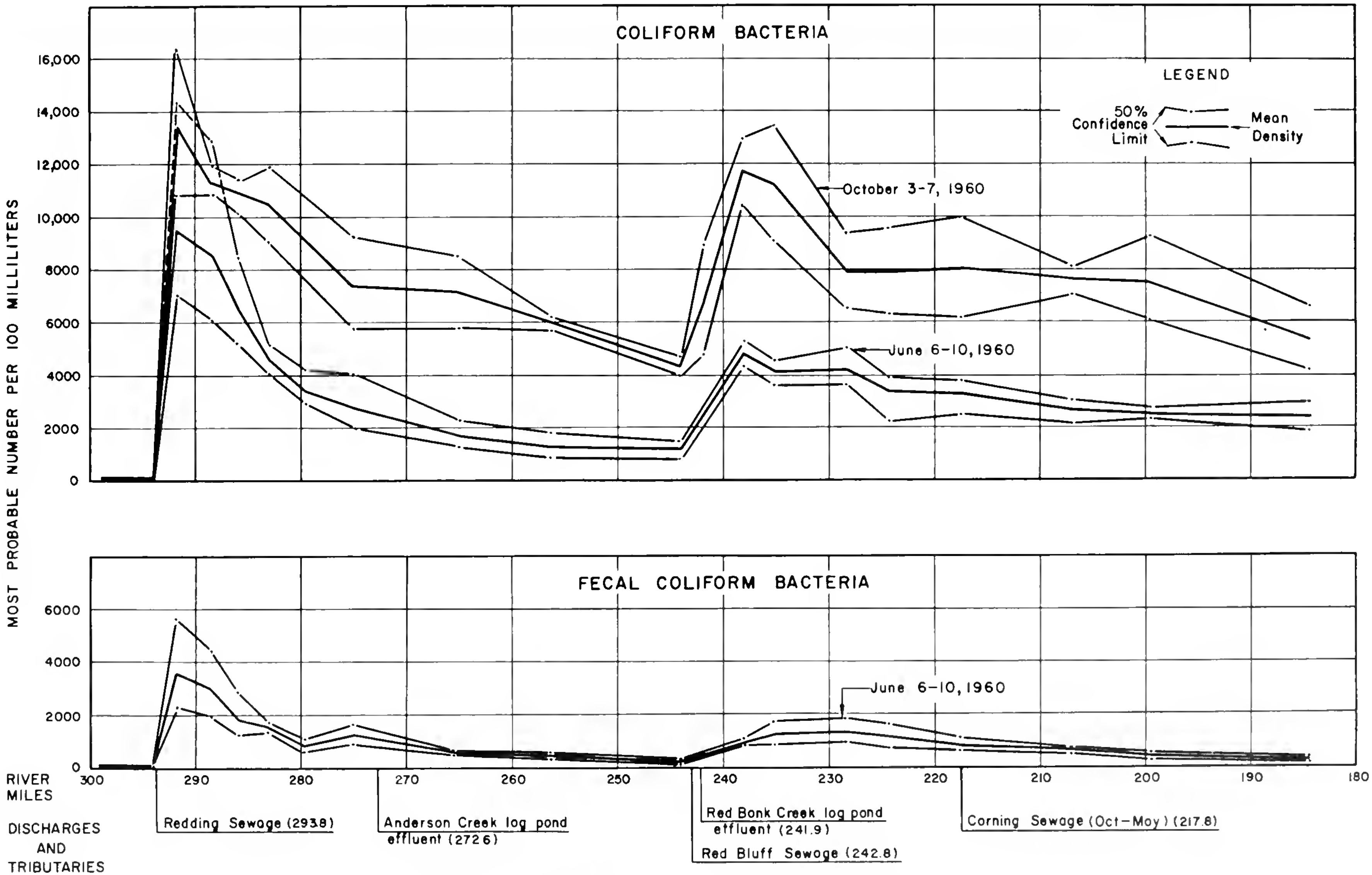
Present knowledge requires that information on bacteriological conditions be obtained from intensive short-term surveys. Accordingly,

samples of Sacramento River water and waste discharges were taken at three-hour intervals during the intensive survey periods:

Upper reach (mile 297.3 - 184.5)	- June 6 - 10, 1960 October 3 - 7, 1960
Middle reach (mile 184.5 - 62.6)	- September 12 - 16, 1960 May 8 - 12, 1961
Lower reach (mile 62.6 - 4.0)	- June 20 - 24, 1960 August 29 - September 2, 1960 October 24 - 28, 1960

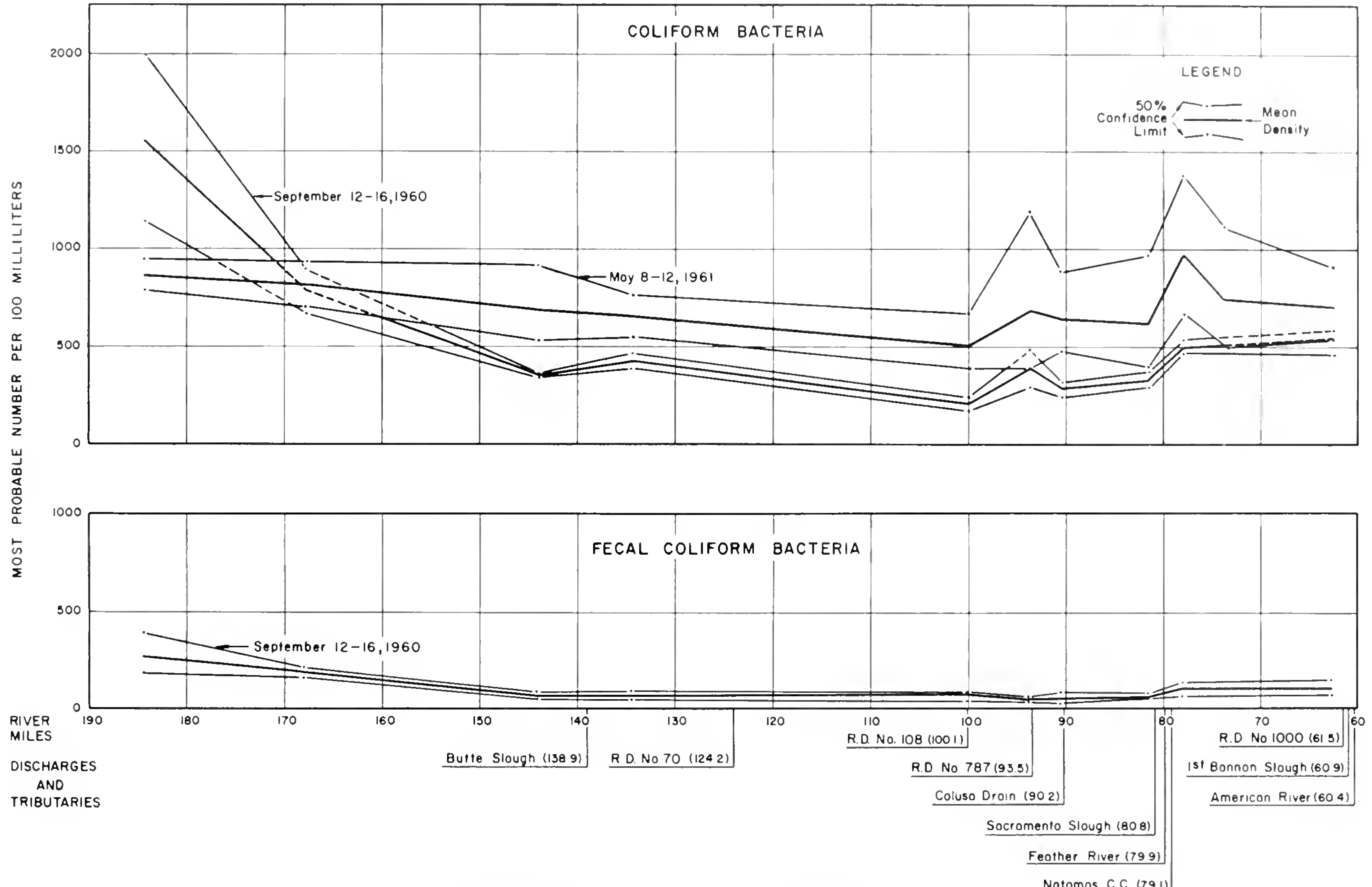
Concentrations of coliform bacteria and of fecal coliform bacteria were determined. The occurrence of either of these groups in water does not of itself mean that pathogenic bacteria are present; rather, the absence of these groups is generally taken to indicate that the water is bacteriologically safe. The standard test for coliform inherently includes some water and soil bacteria that have no sanitary significance. Accordingly, tests to differentiate fecal coliform bacteria by the Eijkman procedure (2) were made. As expected, it was found that the total coliform population in sewage included a high percentage of fecal coliforms. In tributary streams or irrigation waste waters, a lower percentage of fecal coliforms were found. However, these relative percentages were not consistent in the Sacramento River below points of discharge so that observations of fecal coliform densities must be applied with caution.

Figures 5 through 8, inclusive, show the concentrations of coliform and fecal coliform bacteria in the river during the intensive surveys. The statistical significance of the concentrations shown on the figures is discussed in detail in Appendix C. It is sufficient here to note that sewage treatment plant effluents have obvious effects on the bacteriological quality of the river and that these effects are reduced by effluent chlorination.



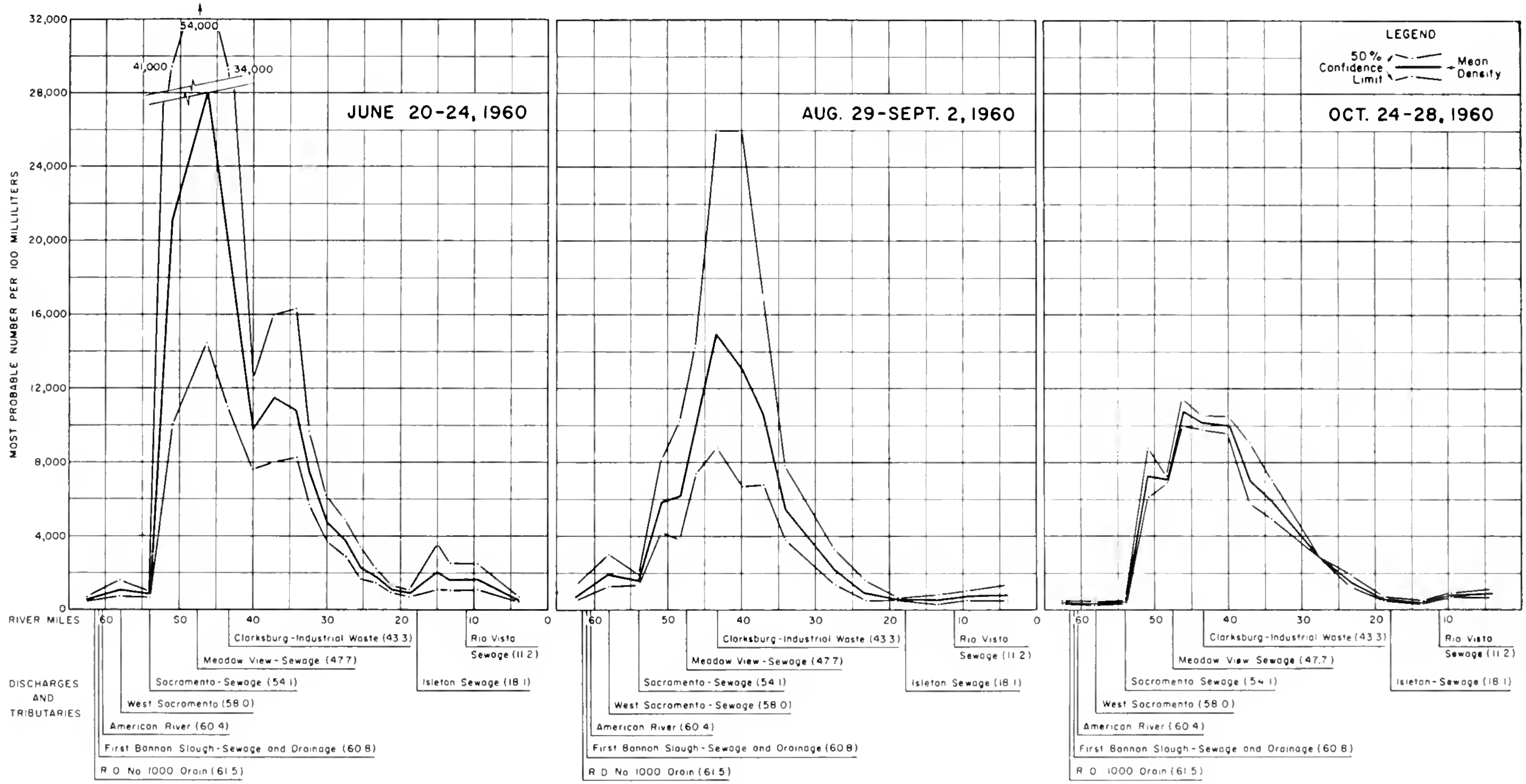
Geometic Mean Density and 50% Confidence Limits

Figure 5. BACTERIA IN SACRAMENTO RIVER — UPPER REACH



Geometic Mean Density and 50% Confidence Limits

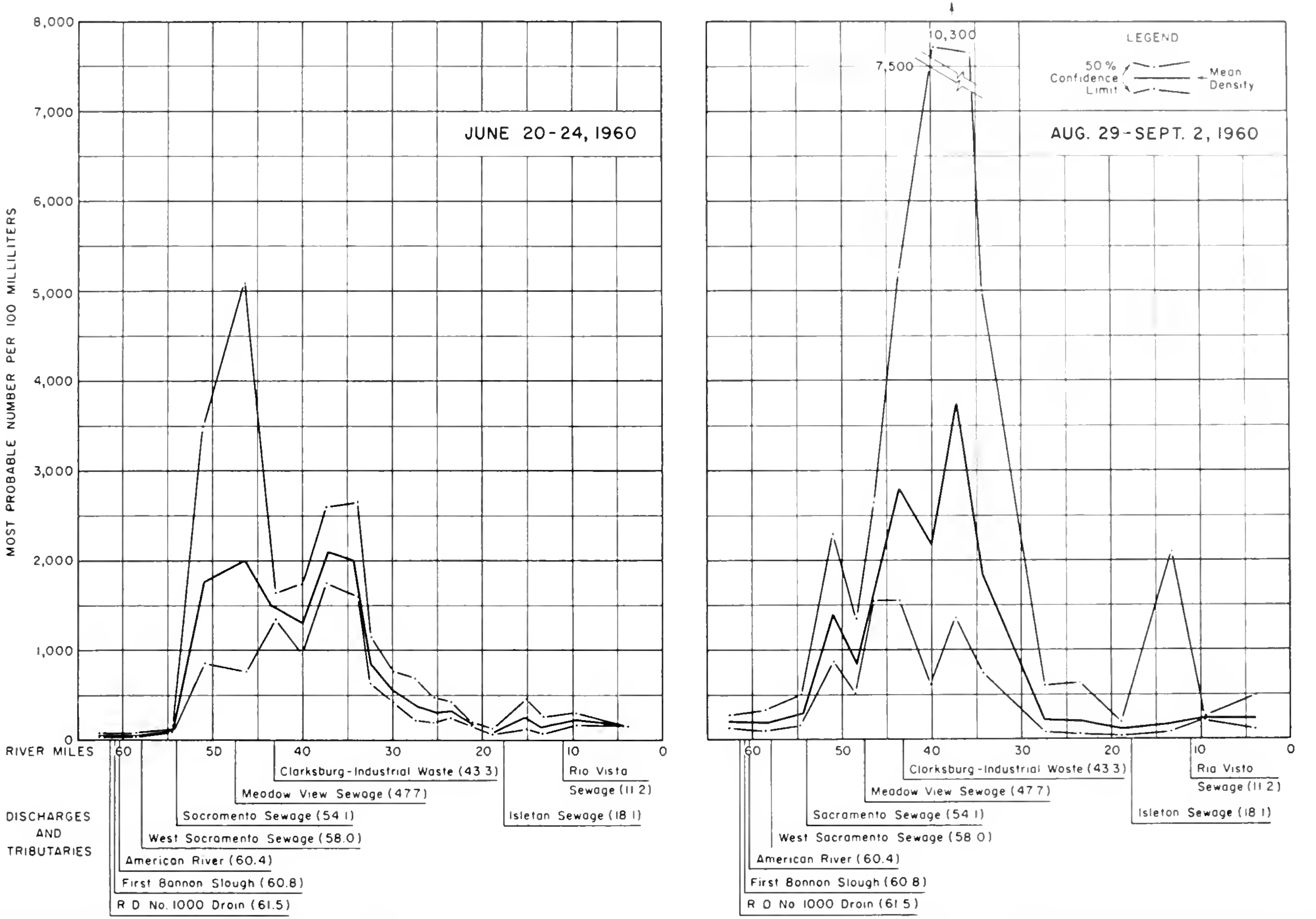
Figure 6. BACTERIA IN SACRAMENTO RIVER—MIDDLE REACH



Geometric Mean Density And 50% Confidence Limits

Figure 7. BACTERIA IN SACRAMENTO RIVER LOWER REACH

COLIFORM BACTERIA



Geometric Meon Density And 50% Confidence Limits

Figure 8. BACTERIA IN SACRAMENTO RIVER LOWER REACH

FECAL COLIFORM BACTERIA

The bacteriological quality of the Sacramento River above the Redding sewage treatment plant discharge was good during the June and October sampling periods. The mean densities of coliform bacteria for the two sampling periods were 50 per 100 ml and 90 per 100 ml, respectively.

Downstream from Redding and Red Bluff, the bacteriological quality of the river water is adversely affected by sewage discharged from the two cities. The highest coliform bacteria populations were found in October when the river flow was low: below Redding, 13,500 per 100 ml and below Red Bluff, 11,100 per 100 ml. Peak fecal coliform densities in June were 3,600 per 100 ml and 1,300 per 100 ml below Redding and Red Bluff, respectively. In all cases the peak coliform bacteria concentrations were found at the first station downstream from the discharges. The fecal coliform bacteria below Red Bluff in June exhibited a nine-hour lag period before reaching peak concentrations.

A flow of 0.25 MGD chlorinated primary effluent from the City of Corning was discharged to the river at river mile 217.6 during the October period without noticeable effect on the river. During June, the effluent was confined to land.

Agricultural drainage discharges in the middle reach of the river (mile 184.5 - 62.5) caused increases in the coliform bacteria numbers in the river immediately below the drains. No similar increases in the fecal coliform concentrations of the river were observed.

The lowest numbers of coliform bacteria in the middle reach were found at river mile 100.2, immediately above the discharge from Reclamation District No. 108. Coliform densities were 250 and 520 per 100 ml in September 1960, and May 1961, respectively. From this point to mile 62.5 north of Sacramento, the coliform level increased to 510

and 700 for the two periods. The increase is attributed to five agricultural drains which discharge to the river between these two points.

In the lower reach, the bacteriological quality shows the effect of sewage effluent discharges in the Sacramento area. The West Sacramento Sanitation District discharge, 2 MGD of disinfected primary effluent, had no noticeable effect on the river water bacteriological quality. The City of Sacramento discharged 40 to 65 MGD of primary effluent which received subresidual postchlorination from the main plant and 0.25 MGD of unchlorinated effluent from the Meadowview plant. The coliform bacteria content downstream from these two discharges was from 10,800 per 100 ml to 28,800 per 100 ml during three sampling periods in June, August-September, and October. The lower peak values occurred when the effluent was more heavily chlorinated. Maximum fecal coliform concentrations were 2,000 per 100 ml and 2,800 per 100 ml during the June and August-September periods. The Meadowview discharge apparently contributed a significant portion of the bacteriological concentrations found downstream from both discharges. Any increase in the bacterial densities of the river caused by waste water from a sugar beet processing plant at Clarksburg was overshadowed by the effects of the upstream discharges. The Isleton and Rio Vista sewage discharges had local effects on the bacteriological quality of the water in June. No effect was noted in the other sampling periods.

The profile of coliform bacteria for June revealed a minor peak at river mile 35 which is 12 miles (10 hours) downstream from the Meadowview sewage discharge. There are no local sewage discharges near mile 35 to account for the peak. The fecal coliform profiles for both June and August-September periods exhibited major peaks at the same point. The downstream displacement of maximum concentrations is caused by "aftergrowth" of the bacteria.

The coliform bacteria content of the sewage discharges ranged from 300 per 100 ml at West Sacramento, with heavy postchlorination, to 39,000,000 per 100 ml at Redding with no chlorination. Coliform bacteria in water from seven major agricultural drains were between 1,180 and 4,600 per 100 ml.

Fecal coliform concentrations in sewage discharges ranged from 80 per 100 ml at the Isleton Sewage Treatment Plant (chlorination) to 14,300,000 per 100 ml at the Meadowview Sewage Treatment Plant (no chlorination). The fecal coliform density of the agricultural drainage water was from 95 per 100 ml to 330 per 100 ml.

There are five domestic water systems that use the Sacramento River as a source of supply. Three of these, Redding Municipal Water System, Rockaway Water System, and the Enterprise Public Utility District System use Sacramento River water above the Redding sewage discharge. The Rockaway system which provides only simple chlorination has exceeded bacteriological limits of the U. S. Public Health Service "Drinking Water Standards". The other two systems that divert water above Redding have met the bacteriological standards. Redding provides chlorination and settling, and Enterprise chlorinates water from an infiltration gallery. Sacramento and Vallejo, the other two systems using Sacramento River water, provide complete water treatment and the finished product has consistently met the "Drinking Water Standards".

The bacteriological quality of the Sacramento River has its greatest significance in connection with recreational activities. Comparison of Figures 5 through 8 with Figure 1, in the preceding chapter, shows that large numbers of people pursue water-contact sports in areas with high bacterial concentrations due to sewage treatment plant discharges. Near Sacramento, one of the most popular sports areas is at Clay Bank

Bend which extends from one-half to two and one-half miles below the outfall from the Sacramento Sewage Treatment Plant; here, detergent foam from the discharge occasionally collects on the banks and the coliform bacteria concentrations range from 6,000 to 20,000 per 100 ml. No epidemiological studies have been made, and no bacterial standards for fresh water recreation areas have been adopted by the State Department of Public Health. However, the presence of foam and high bacterial numbers indicated that a higher degree of sewage treatment and disinfection is needed in the Sacramento area.

Stream Biology

Both plant and animal life are found within a stream. Some of these are floating or weakly swimming (plankton) and others are attached or burrowing (benthos). The forms of life vary from the simple to the complex. Photosynthetic plants range from single-celled floating algae to such flowering plants as pond weeds. Similarly, animals range from single-celled protozoans through worms and insects to fish. Stream life also includes non-photosynthetic plants such as bacteria or fungi and photosynthetic protozoans.

Only a fraction of the life within the Sacramento River has been studied during the present survey. Of the bacteria, only those of sanitary significance which are easily enumerated have been investigated.

Plankton have been identified, counted, and reported in accordance with the method followed by the U. S. Public Health Service for the national stream monitoring network.

Bottom (benthic) animals have been sampled and enumerated by methods outlined in Standard Methods (2) or Welch (47). The identification of many of the benthic organisms has been complicated by the discovery

of previously unreported species and has been hampered by the lack of suitable handbooks or keys. The identifications which were made were based upon the most recent systematic classifications available.

Investigations of native bacteria, fungi, benthic protozoans, and fish within the river were beyond the scope and funding of the investigation. The survey did include, however, those aspects of stream biology which are traditionally studied in pollution investigations.

Plankton

Samples collected from 22 monthly stations were preserved and examined for plankton at the Berkeley laboratories of the State Department of Public Health. Figure 9 summarizes the observations of total plankton found in the 265 samples collected from April 1960 through June 1961. The lowest concentrations, throughout the river, were found in the winter months. During the rest of the year, plankton populations increased from a few hundred individuals per milliliter at Keswick to as many as 15,000 per milliliter in the lowest reach. Figure 9 shows that increases typically occurred below the Redding, Red Bluff, and Sacramento Sewage Treatment Plants. The blooms which occurred in late spring or early summer of both years are characteristic of natural streams.

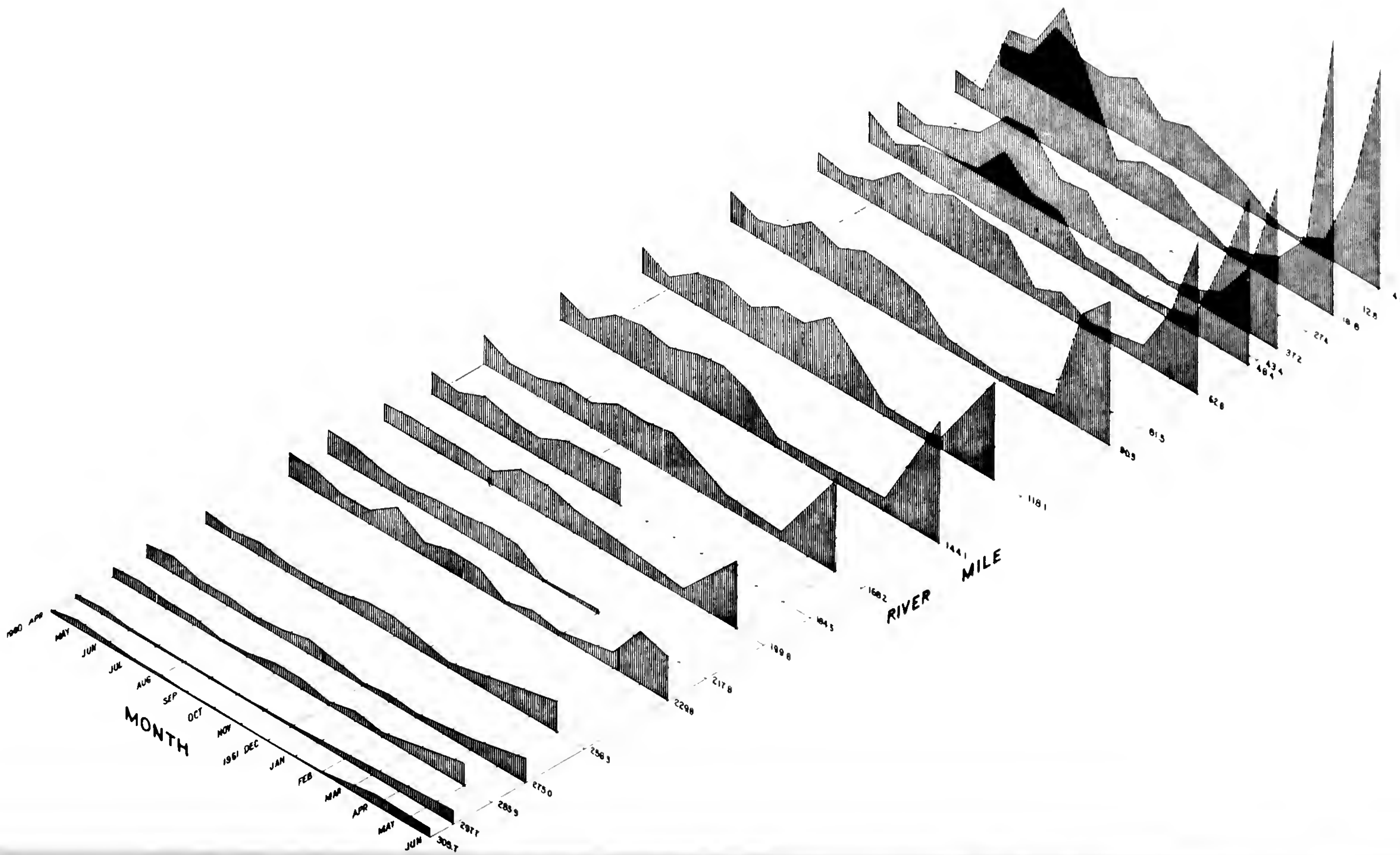
Essentially all of the plankton consisted of algae, particularly the diatoms *Synedra*, *Cyclotella*, and *Melosira*. Blue-green and other algae were found in low concentrations. Zooplankton, that is, animal plankton, generally comprised between zero and one percent of the total; these low percentages might reflect the difficulty in recognizing many of the protozoans in the preserved samples.

Statistical analyses of plankton populations showed a high degree of correlation with water temperatures and very little correlation with

Figure 9.

SACRAMENTO RIVER. PLANKTON, TOTAL PLANKTON PER ML
BY MONTH AND STATION

VERTICAL SCALE | EACH SCALE DIVISION = 100 PLANKTON PER ML



stream flow, The reasons for and the significance of the more intense bloom that occurred in 1961 as compared with 1960 are unknown.

Since it is known that most algae require certain growth factors, a limited study of vitamin B_{12} was made in June 1961. In the river, vitamin B_{12} increased from 0.002 to 0.013 millimicrograms per liter (mug/l) between mile 297.7 (at Redding) and mile 81.5 (above Colusa Basin Drain), respectively, and remained relatively constant thereafter. In sewage effluents, B_{12} varied from 0.60 to more than 1.0 mug/l and in Colusa Basin Drain, a concentration of 0.022 mug/l was found.

Comparison of plankton with nitrogen and phosphorus concentrations showed no consistent relationship except, as previously noted, a rough correlation with organic nitrogen.

The high algae concentrations found below Sacramento indicate a possibility of rapid clogging of filters and taste and odor problems in domestic water purification systems.

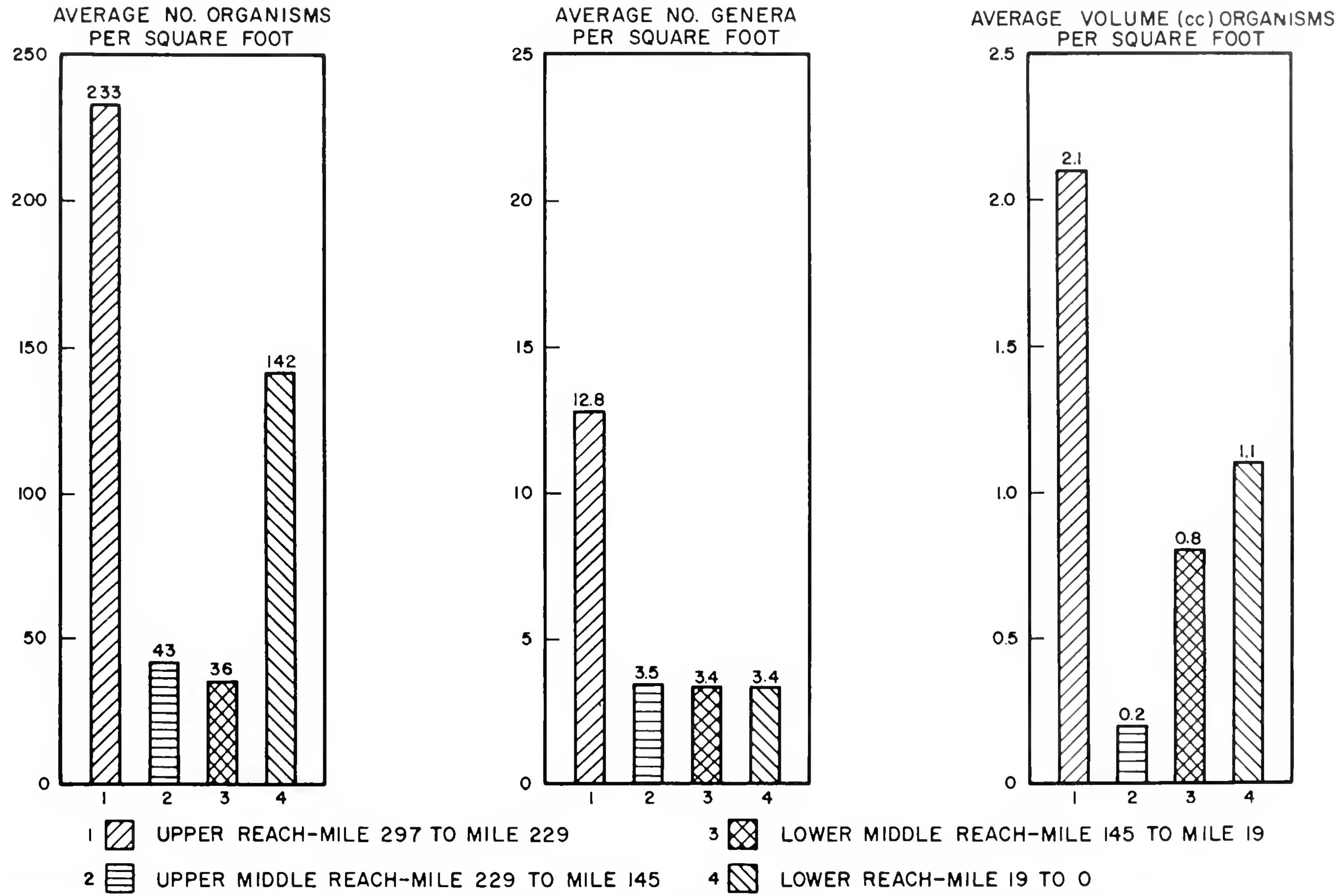
Benthos

Benthic or bottom organisms were collected at 29 river stations at monthly or bimonthly intervals between Keswick (mile 305.7) and Mayberry Slough (mile 4.0). The reference collection is stored and maintained at the California Department of Fish and Game field station at Sacramento. The results in terms of variety and abundance are summarized in Figure 10.

The figure shows that the upper and extreme lower reaches contained the greatest total number and mass of organisms and that the middle reach of the river was relatively barren. The limited populations in the middle reach are ascribed to the nature of the sediments, which constitute an unstable or shifting bottom. In the upper and middle reaches, the bulk of the benthic organisms were the larval and pupal stages of

Figure 10.

NUMBERS, DIVERSITY AND VOLUMES OF AQUATIC ORGANISMS
APRIL, 1960 THROUGH JUNE, 1961



insects. In the lower reach, most of the animals were molluscs (clams) and oligochaetes (worms). The greatest diversity of animals was found in the upper reach.

Seasonal variations in total population density and composition have not been evaluated although new information on the life cycles of some of the insects was developed.

It was found that areas of riffles or rapids supported the largest and most varied populations. Because of the importance of the area for salmon spawning, particular attention was given to spawning gravels above mile 229.8 (Elder Creek). Dissolved oxygen concentrations in interstitial waters of these gravels varied from 4 to 12 ppm while the overlying waters contained 9.5 to 12 ppm. Large differences in gravel dissolved oxygen occasionally occurred over a few feet. The lower concentrations were generally found at sampling locations where there was a relatively large amount of silt in the gravel. This may explain why successful salmon spawning occurs in very localized areas within a general spawning reach.

Because the Sacramento River Water Pollution Survey included the most intensive effort on benthic biology made to date on the river, knowledge of living organisms within the river was greatly increased. The geographical distribution of a number of forms was established; for example, an amphipod (related to the ubiquitous sand flea found along the ocean shore) which had previously been assumed to occupy only brackish waters, was consistently collected 80 miles upstream at Verona and was even found 118 miles upstream at Wilkins Slough. In spite of the fact that little effort in detailed taxonomic work was possible, several forms were recorded for the first time in California waters.

Considerable effort was directed toward correlating water quality and "pollution indicators". Such knowledge would be valuable in relating specific waste discharges to aquatic life in that a pollution-tolerant organism is an accumulating device which gives a measure of past water quality conditions in the river. However, there was no indication that waste discharges had any measureable effect on the abundance or distribution of organisms in the river. Some forms, such as midge larvae, which have been cited in the literature as indicating pollution, were found in locations where no pollution was possible. The findings, which are summarized on Figure 10, can be attributed to natural conditions unrelated to waste discharges.

The main value of the observations of benthic biology made during the present investigation will be realized in future years when the effects of water quality degradation due to additional development in the Sacramento Valley can be quantitatively assessed. To this end, additional study and cross-correlations of the existing data are required, and further taxonomic study of the reference collection is warranted.

Future biological investigations of the scope of the present survey should provide, for each man-day spent in the field, from three to five man-days in the laboratory. In addition, a minimum of two man-days of professional time in the office for each day in the field are required from the outset of the investigation for evaluation of the data, and at least two more man-days are required during the final evaluation and report-writing stage.

Findings of the biological portion of the Sacramento River Water Pollution Survey, viewed in light of presently anticipated development in the Sacramento Valley, indicate that future comprehensive investigations should be made at intervals of about five years. Local studies

of an operational nature which relate to specific waste discharges must, of course, be scheduled as needed.

Oxygen Relationships

A high level of dissolved oxygen contributes to the potability of a domestic water supply and assists in the stabilization of organic material with the result that a stream is pleasing to look at, sustains desirable fish and aquatic life, and promotes recreational activities.

Sources of Pollution

During the Sacramento River Water Pollution Survey, monthly observations were made of flows and 5-day biochemical oxygen demand (BOD) loadings from municipal and industrial waste discharges and from irrigation returns (Plate 1). The natural BOD in the stream was also determined. The most complete data were obtained during intensive surveys. BOD loadings in discharges ranged from a few percent of the natural BOD in the stream for the smaller plants to one to two times the natural BOD for the City of Sacramento's main sewage treatment plant. The highest BOD loadings on the river occurred during the late summer and early fall.

Dissolved Oxygen

Concentrations and saturation values of dissolved oxygen were obtained monthly and during intensive 4-day sampling periods. Although the monthly data were used in one evaluation of oxygen relationships in the lower reach, the best information on oxygen levels throughout the river was derived from the intensive sampling surveys.

Figure 11 shows average temperature and dissolved oxygen in the Sacramento observed on the seven intensive surveys between May and October. Although gross seasonal differences are apparent on the figure,

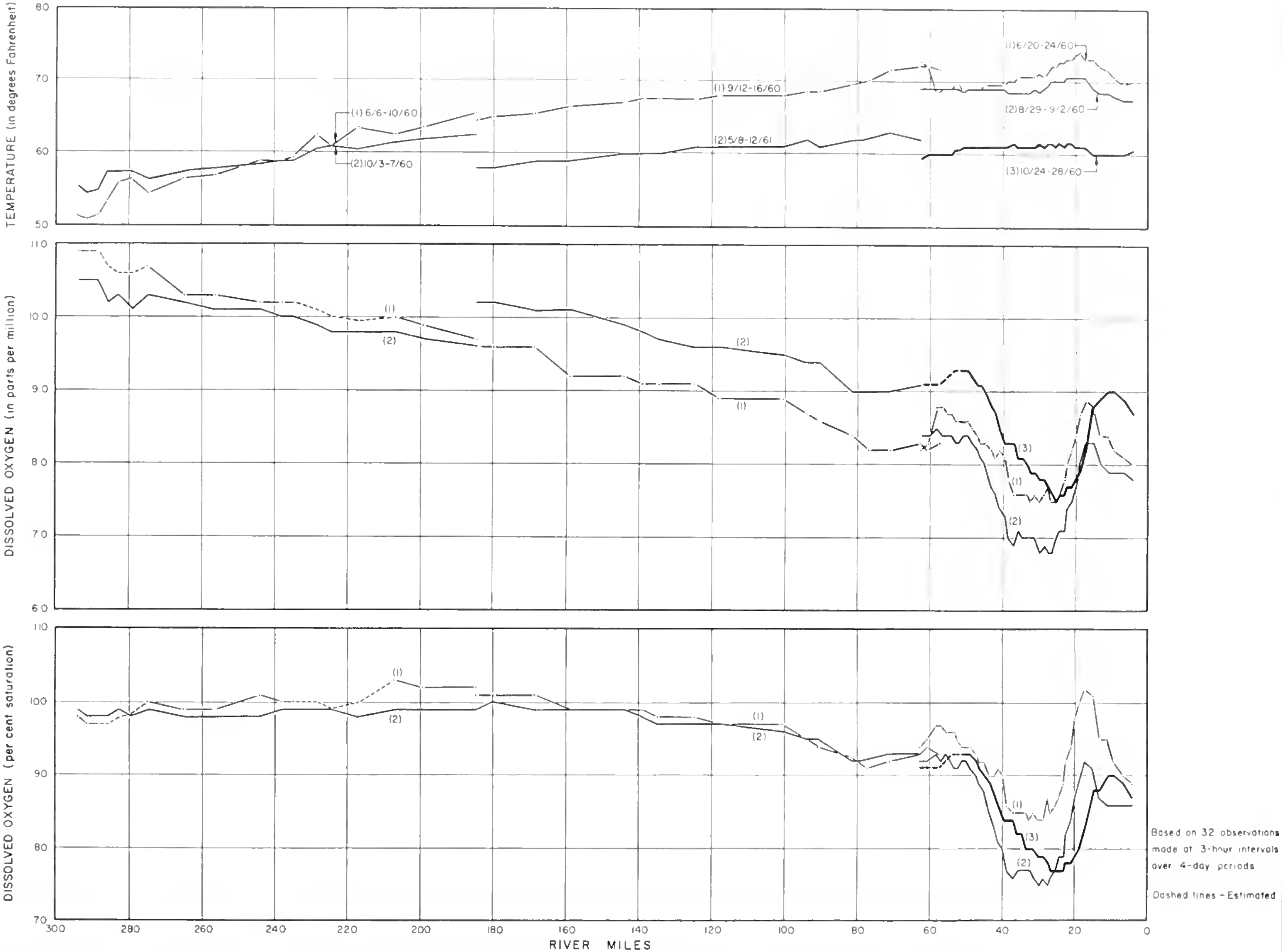


Figure 11. AVERAGE WATER TEMPERATURE AND DISSOLVED OXYGEN IN SACRAMENTO RIVER
LATE SPRING TO FALL

the data are nevertheless consistent, and clearly show the overall pattern of oxygen levels in the river. Oxygen concentrations were between 10 and 11 ppm near Redding and decreased more or less uniformly throughout the river. The oxygen sag near Walnut Grove due to upstream waste discharges is apparent, with averages between 7 and 8 ppm and minimum concentrations (which are not shown) between 5.2 and 6.5 ppm. The 5.2 ppm is close to the 5 ppm cited earlier as being the limiting value for fish migration. Saturation values started at 98 or 99 percent, rose somewhat within the upper reach where the effects of heating were dominant, and then began a steady decline to the mouth.

On the whole, the river loses oxygen from Redding (mile 297.7) to Mayberry Slough (mile 4.0). Waste discharges cause sags in oxygen levels which are superimposed upon the overall pattern of decreasing oxygen.

Diurnal Variations

An unexpected result of the intensive surveys was the observation of frequent departures of diurnal variations in oxygen levels from the classical pattern. It is generally assumed that dissolved oxygen is at a minimum just before dawn, increasing during the day due to photosynthetic activity of algae, reaches a maximum about mid-afternoon, and then decreases to the pre-dawn minimum. This classical pattern was found, particularly in the upper reach, but as the river flowed downstream departures from this pattern increased. Minimum values occurred all the way from 1 or 2 a.m. to noon, and maxima often persisted well past sunset. Increases were found at night when there could be no photosynthesis. Completely inverted curves, with maxima at about midnight and minima at midday were observed. These variations are attributed to changes in

biological activity which have important consequences in evaluating the waste-assimilative capacity of the river.

Characterization of Oxygen Relationships

Oxygen Sag Analysis. Since 1925, the method of Streeter and Phelps (40) has been the standard for describing oxygen conditions in a stream below a waste discharge and for determining the waste assimilative capacity of a stream. The method, which is described in detail in Chapter V, Appendix B, relates the rates of deoxygenation to the rates of atmospheric reaeration. The rate of deoxygenation is assumed directly proportional to the amount of BOD, and the rate of reaeration is assumed proportional to the saturation deficit. The deficit equals the difference between the actual oxygen level and that which would occur if the water were saturated.

Since 1925, the major effort in stream sanitation has been directed towards determining the rate constants, which were known to vary from different wastes and streams, to be inserted into the Streeter-Phelps formulation.

The rate of deoxygenation is determined for laboratory tests which are assumed to be applicable to stream conditions. That they are not has been apparent from a number of failures of the method (42). The reason for these failures lies in the observed departures of diurnal oxygen variations from the classical pattern noted above; biological (or biochemical) activity in a stream is not a simple function of the BOD of food supply. From time to time, plants or animals in the stream rest and, accordingly, utilize oxygen and stabilize wastes at lower rates.

The rate of reaeration may be calculated from the rate of deoxygenation applied to observed river conditions, or may be derived

independently. However, the assumption that this rate is dependent upon the saturation deficit neglects photosynthesis.

An effort was made to characterize the oxygen relationships and to determine waste assimilative capacity in the Sacramento River below Sacramento by the Streeter-Phelps method and by various modifications thereof proposed by Streeter (41), O'Connor and Dobbins (39), and Churchill (36). These computations typically resulted in negative values for the reaeration coefficient which have no physical meaning.

Multiple Linear Correlation Analysis. Somewhat better success was obtained by applying the statistical method of Churchill (35) to the monthly data from April 1960 to June 1961 on flows, temperatures, oxygen levels, and total waste loadings in the lower reach. Application of the numerical factors derived from the linear correlations to the conditions observed during the three intensive surveys on the lower reach resulted in excellent agreement for the September 29 - October 2, 1960 period, but gave unsatisfactory results for the other periods. It follows that, in order to make this method generally applicable, the correlations must be expanded to include variations of algae populations, relative amounts of wastes from individual sources and other factors. In addition, the linearity of the interrelationships should be confirmed.

Diurnal Curve Analysis. In 1956, Odum (37) published a new method for determining the amounts of oxygen supplied by or lost to the atmosphere, added by photosynthesis, and utilized by respiration. Respiration is identical with BOD satisfaction and includes the deoxygenation of Streeter and Phelps. In addition, the effects of bottom organisms or deposits (benthic demand) are included. The basis of the method is

summarized in Chapter V, Appendix B, and is presented in detail in Odum's publications (37, 38).

The diurnal curve analysis could not be applied to all of the data collected during the intensive surveys. The method inherently involves some simplifying assumptions and fails completely where maximum dissolved oxygen is found at night.

Figure 12 shows rates of photosynthesis, respiration, and net inward diffusion between Sacramento (mile 62.6) and Mayberry Slough (mile 4.0) during the three intensive surveys in the lower reach. Values are reported in grams per square meter per day which can be multiplied by 8.93 to give pounds per acre per day. In addition to local variations due to individual waste discharges, photosynthesis and respiration rates increase throughout the degradation portion of the oxygen sag curve, decrease in the sag portion, and increase in the recovery portion of the curve. The figure shows that in the degradation phase, respiration is greater than the sum of diffusion plus photosynthesis and oxygen levels in the stream decrease. Where respiration approximately equals diffusion plus photosynthesis, as in the sag portion, oxygen levels are essentially constant and where diffusion plus photosynthesis exceed respiration, oxygen levels in the stream recover and approach initial concentrations.

The numerical values of diffusion, photosynthesis, and respiration show a high degree of correlation with physical and biological conditions in the river and qualitatively demonstrate the response of the stream to waste discharges. It has not been possible to compute satisfactory oxygen balances for the river below Sacramento and these values must therefore be considered as only semiquantitative. As with the other methods of characterizing oxygen relationships and estimating waste

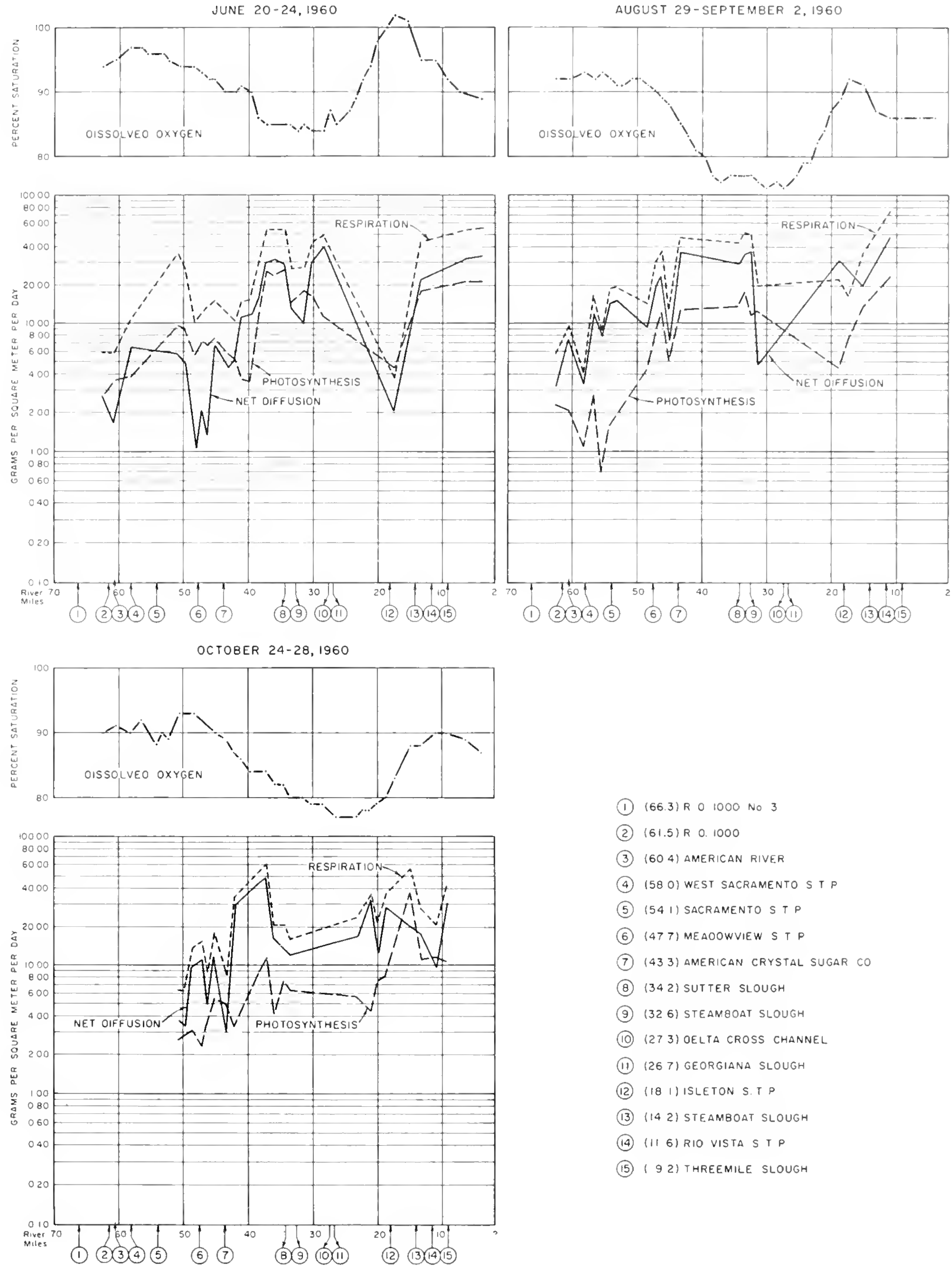


Figure 12. PHOTOSYNTHESIS, RESPIRATION, AND NET DIFFUSION IN THE SACRAMENTO RIVER BELOW SACRAMENTO

assimilative capacities, the greatest uncertainty lies in the evaluation of rates of respiration or BOD satisfaction.

Future Work. The diurnal curve analysis method is considered to have the greatest potential for determining true oxygen balances and, ultimately, the best procedure for calculating the waste assimilative capacity of the Sacramento River. The method inherently describes conditions as they actually occur in the river. However, intensive surveys are required throughout wide ranges of flows and temperatures in order to be able to predict rates of diffusion, photosynthesis, and respiration under future conditions below Sacramento. In particular, more adequate data on respiration are required.

CHAPTER VI. WATER QUALITY MANAGEMENT

The full development of California's water resources requires the construction of additional impoundments within the Sacramento Valley and the diversion of additional waters from north coastal area of the State into the valley (26). Some of the additional supply will be used within the valley to meet the additional demands discussed in Chapter III, and the balance will be exported to central and southern California. The additional domestic, agricultural, and municipal uses of water in the Sacramento Valley will result in additional requirements for waste disposal. The safeguarding of the quality of Sacramento River water for both local use and export requires a management program which will permit maximum utilization of this resource. The requirements for future monitoring of the river and its influents in order to maintain optimum water quality conditions must be rigorously established. For conservative constituents, such as chlorides, a logical data program can best be based upon salt-routing or materials balance techniques. For nonconservative constituents, such as dissolved oxygen, and for biological conditions, the data program involves less exact methods based upon continuous evaluation of current conditions. The public health significance of water quality and water utilization and their relationships to water quality management are discussed in detail in Chapter IV, Appendix C.

Conservative Constituents in the Sacramento River

In a natural stream, concentrations of dissolved minerals are inversely proportional to flows so that the poorest quality is found at low flows. In a regulated stream, the quality is relatively constant regardless of the flow. In the Sacramento River, unregulated tributary

flows tend to develop the typical inverse flow-concentration relationship; however, this relationship is neither well defined nor stable, since it is dependent upon which of the tributary streams and irrigation return flows are predominating at a given time.

Within limits which depend upon the particular drainage basin and the degree of agricultural and urban development, a positive relationship between the specific conductance and the concentrations of various salts is found. Since the former is readily determined and may be continuously recorded, the relationships between flows and specific conductance of the Sacramento River during 1960 were examined by means of a mathematical model. During this period, water quality conditions were within 10 percent of the 20-year mean and hydrologic conditions were within 25 percent of the 50-year mean. This indicates that 1960 adequately represented normal conditions. Further, these relationships suggest that water quality varies over a much smaller range than stream flows, a conclusion that is supported by independent analyses of flow and quality.

The computations, which are discussed in detail in Chapter VI, Appendix B, showed that concentrations of dissolved minerals can be computed to an accuracy which is limited primarily by the completeness of data on tributaries and waste discharges. The results indicated that essentially all of the increases in dissolved minerals below Keswick were contained in less than 20 percent of the accreting flows. There are about 70 sites of accretion or depletion along the river, any one of which is capable of exerting a significant effect on the river's dissolved mineral content. The relative magnitude of these effects are variable and, with present knowledge, not predictable to an adequate degree of reliability. It was found, however, that influent ground waters above Butte City contribute about 5,000 tons of dissolved solids per month to the river.

The present monitoring program, which has been conducted since 1951, and the Sacramento River Water Pollution Survey clearly indicate that future emphasis should be placed on study of conditions affecting flow and mineral concentration of the tributary sources, rather than continuing attempts to study effects of the tributaries upon the Sacramento River. A knowledge of the factors affecting flow and mineral concentrations of the various tributaries, together with the existing knowledge of the tributaries' combined effect on the Sacramento River, would constitute a sound basis for making short and long-term predictions of water quality conditions. The requirements for these predictions, for determining long range rates of accumulation or leaching of salts from soils, and for maintaining current information on water quality in the river can be met by the monitoring program outlined in Table 19, evaluated in conjunction with water quality data obtained from within the tributary watersheds.

The program outlined in the table provides varying degrees of coverage on inflows from 95 percent of the natural drainage area above Sacramento and on the water from the Trinity Diversion. Although some new permanent stations are added, the ultimate effect will be a reduction in the department's surface water quality monitoring program for the Sacramento River. Temporary stations are shown for tributaries where supplemental data are required. On the main stem of the river, additional temporary stations will provide continuity and checks on calculated water quality.

The program outlined herein will provide adequate monitoring data as well as the background for predictions of future mineral quality in the river. A necessary element in the revised program is the continuing

Table 19

RECOMMENDED WATER QUALITY MONITORING PROGRAM FOR THE SACRAMENTO RIVER

Station	(SWQMP No.)	Mile	Conductivity Recorder (a)		Cooperative: USGS Daily Station		Monthly Sampling Station (Partial Mineral)		Semiannual Complete Mineral		Sampling Trace Elements		Dissolved Oxygen Recorder	Carbon Filter	Monthly Algae Analyses
			Perm.	Temp.	Perm.	Temp.	Perm.	Temp.	Perm.	Temp.	Perm.	Temp.	Perm.	Perm.	Perm.
Sacramento River															
Keswick	(12)	300.9		x			x								
Bend	(12c)	256.3			x						x				x
Hamilton City	(13)	199.6								x		x			
Butte City	(87a)	168.2			x						x				
Colusa	(13b)	144.1								x		x		x	x
Boyers Pump	(14)	111.6								x		x			
Sacramento Weir		63.6	x				x		x		x		x(b)	x	x
Freeport	(15b)	46.4			x						x				
Walnut Grove		27.4	x				x		x		x		x	x	x
Rio Vista	(16)	12.8						x		x		x			
Tributaries and Irrigation Drains															
Spring Creek at Mouth		302.3R					x		x		x				
Clear Creek at Mouth		288.1R						x		x		x			
Cow Creek at Mouth		278.9L					x		x		x				
Cottonwood Creek	(12b)	272.4R		x			x		x		x				
Battle Creek	(88b)	270.1L						x		x		x			
Antelope Creek	(88c)	233.5L						x		x		x			
Mill Creek	(88)	229.0L						x		x		x			
Thomes Creek	(95b)	224.4R						x		x		x			
Deer Creek at Mouth		219.1L						x		x		x			
Big Chico Creek	(85a)	193.9L						x		x		x			
Stony Creek	(13a)	190.8R		x			x		x			x			
Butte Slough at Outfall Gates		138.9L		x			x		x			x			
R. D. 108 Drain at Pumps		100.1R		x			x		x			x			
Colusa Basin Drain at Mouth		90.2R		x			x		x			x			
Sacramento Slough	(14a)	80.8L		x			x		x			x			
Feather River at Mouth		79.9L		x			x		x		x				
R. D. 1000, Pumping Plant No. 3		66.3L						x		x					
R. D. 1000, Natomas Main Canal at Mouth		61.5L						x		x					
Natomas East Main Drain at Mouth		60.6L						x		x					
American River	(22)	60.4L					x		x		x				

Note: (a) Water temperature recorders at stations where other types of recorders are in operation.
(b) DO recorder to be located between mile 54.2 and mile 55.

analysis of current data so that monthly reports on water quality in the river can be published in the minimum time.

The partial mineral analyses include determinations of specific conductance, pH, calcium, sodium, carbonate, bicarbonate, chloride, boron, percent sodium, carbonate and noncarbonate hardness, and turbidity.

Complete mineral analyses include, in addition to those in the partial analyses, determinations of magnesium, potassium, sulfate, nitrate, fluoride, silica, phosphate, and total dissolved solids.

Analyses for trace elements include determination of aluminum, beryllium, bismuth, cadmium, cobalt, chromium, copper, iron, gallium, germanium, magnesium, molybdenum, nickel, lead, silver, titanium, vanadium, and zinc by spectrographic methods. Wet chemical procedures are used for arsenic and selenium.

Analyses at the cooperative USGS daily stations include determinations of specific conductance, pH, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, boron, nitrate, fluoride, and carbonate and noncarbonate hardness, and silica.

Nonconservative Constituents and Biological Characteristics

Concentrations of dissolved oxygen, organic materials, and alkalinity vary seasonally and diurnally because of biological activity. Temperatures vary seasonally throughout the river and diurnally to a degree which is controlled by local hydrographic conditions. In general, intensive short-term studies in selected areas at critical periods of the year are the major sources of information required for water quality management. Continuous monitoring of certain constituents identifies needs for intensive surveys and provides supporting data. The following monitoring program will provide the minimum amount of data required:

Temperature	- Continuous recorders at all stations where other types of recorders are or will be in operation.
Dissolved Oxygen	- Continuous oxygen analyzers are required at Sacramento (mile 63.6) and Walnut Grove (mile 27.4). At intervals of about two years, dissolved oxygen levels in the lower reaches of the Sacramento and American Rivers should be obtained from intensive surveys during the critical month.
pH and Alkalinity	- To be determined during intensive surveys.
Nitrogen Series	- To be determined during intensive surveys.
Organic Materials	- Permanent installations for determination of organic materials by the carbon adsorption method should be provided on the Sacramento River at Colusa (mile 144.1), Sacramento (mile 63.6), and Walnut Grove (mile 27.4) and on the American River near the mouth.
Algae	- Monthly analyses of the Sacramento River at Bend (mile 256.3), Colusa (mile 144.1), Sacramento (mile 63.6), and Walnut Grove (mile 27.4) are required.
Bacteriological Quality	- Sampling requirements for bacteriological data can be met during intensive surveys of oxygen relationships.
Minor Constituents	- Analyses for ABS and phenols are made semi-annually for monthly stations listed in Table 19.
Benthic Biology	- At about 5-year intervals, collect bottom organisms from 28 biological stations (Appendix D) throughout river. Sample bimonthly for a one-year period.

Special Investigations

In addition to the programs outlined above, the Sacramento River Water Pollution Survey has indicated the need for additional analysis of the data collected during the survey and for special studies as follows:

Continuous conductivity recorder data obtained during the present investigation should be analyzed to evaluate vertical and longitudinal

mixing. In addition, the use of conductivity recorders to investigate travel times, flow distribution, and mixing in waterways of the Sacramento-San Joaquin Delta should be evaluated.

A special study of water temperatures and heat balances throughout the Sacramento River system, including the Sacramento-San Joaquin Delta, should be made to provide criteria for reservoir operations, to estimate the capacity of the river to assimilate thermal pollution, and to provide data on mixing.

The most critical dissolved oxygen conditions in the river are and will continue to be caused by waste discharges in the greater Sacramento area. Accordingly, special two-day intensive surveys of oxygen relationships in the river between Sacramento and Rio Vista at monthly intervals should be conducted for a two-year period. This will provide correlation factors for predicting future dissolved oxygen levels.

After the basic monitoring program for conservative constituents outlined in Table 19 has been in operation for one year, predictions of future mineral quality conditions in the Sacramento River should be made. These predictions should be made biennially and should include consideration of a Sacramento Valley master drainage system.

Future investigations which are similar in scope to the Sacramento River Water Pollution Survey should provide for about two man-days on data evaluation for each man-day in the field, concurrently with the data collection phase. During the final data evaluation and report writing phase, an additional two man-days in the office are required for each man-day in the field. These ratios do not include laboratory requirements.

SUPPLEMENT

WATER QUALITY AND THE PUBLIC HEALTH

Reproduced from Appendix C, "Public Health Aspects"

WATER QUALITY AND PUBLIC HEALTH

The public health interests in water quality are manifold, since many of the physical, chemical, and biological properties of water determine its suitability for drinking, recreation, and the preparation or growing of foodstuffs.

Man's drinking water must be free of disease-producing organisms and chemical substances that are harmful. It should be cool, clear, and free of odors and tastes. It should be suitable for all household purposes such as culinary use and the washing of clothes. Domestic water should not stain, corrode, or foul pipes or plumbing fixtures.

Waters used for aquatic sports must be safe not only from the standpoint of disease transmission but also reasonably free of accident hazards. Clarity of recreational waters should be such that submerged logs and rocks are visible to bathers, and not so turbid that swimmers and divers cannot be readily seen by lifeguards.

Food crops must not be contaminated by waters used for their irrigation. The foodstuffs which are usually eaten raw are of particular concern if they should be wetted by water which has been contaminated by sewage. Water used in the processing of foods also must be free of filth and disease-producing organisms.

Devastating epidemics of typhoid and other "water-borne" bacterial diseases are now a matter of history in the United States, due to the application of knowledge, continuously growing, in the sanitary sciences and preventive medicine. In large part, the near eradication of "water-borne" bacterial diseases is due to progress in water purification and pollution prevention, control, and abatement. The threat of "water-borne" disease, however, will persist as long as wastes from the human body are placed where they may find their way into man's sources of water.

At the present time, increasing attention is being directed toward viruses and the role water and sewage may play in transmission of virus diseases. Within the past few years about 75 enteroviruses, those found in the intestinal tract and sewage of man, have been identified, though not all have yet been associated with specific diseases. It is known that conventional water treatment practices are not sufficient to destroy certain of these viruses which are found in human excreta. Of particular concern is the virus of infectious hepatitis. Overwhelming evidence has established that this disease can be "water-borne", but laboratory methods have not yet been found to isolate the causative organism of this disease. Until laboratory techniques have been developed which will ascertain the type and degree of treatment that is necessary to destroy hepatitis, control must depend on judgements based on experience.

Also of concern is the presence of the new types of chemicals in sewage, industrial wastes, and land drainage. Typical of these new contaminants resulting from our dynamic industrial technology are radioisotopes, synthetic detergents, and pesticides. Accurate laboratory methods have not been developed to identify or measure the amounts of most of these new chemicals that now may be reaching our waterways. Some of the synthetic organic chemicals do not break down in receiving waters, nor are they removed by normal sewage or water treatment methods. The subtle and long-range effects of these new chemicals on the public health must be learned, and threshold limits established. Until this is done, policies must necessarily be conservative.

The common mineral constituents in water originating in the geological formations through which the water passes and, frequently, from agricultural waste waters, are also of public health concern. High levels of sodium cannot be tolerated by people suffering from certain

heart and kidney diseases, and by many pregnant women. Such people must carefully limit their total sodium intake, including that portion contributed by their drinking water. Natural waters high in sodium are not often suitable for such people, and alternate water sources are necessary. Excessive amounts of fluorides in water will have major detrimental effects on the physical structure of teeth of children drinking such waters. In addition to these, and possibly other adverse physiological effects, waters high in total minerals (including chlorides, sulfates, and magnesium) have a brackish, salty or bitter flavor, and at higher levels are most unpalatable and therefore unacceptable to the public. Flavor of water is of particular significance since the State Board of Public Health, in granting permit for domestic water supply, must find that the water delivered will, among other things, be wholesome and potable. Only costly demineralization processes will remove such undesirable common minerals.

In addition to the ideas already expressed, the following are axioms that are fundamental to the public health interest in water quality.

1. In order to serve the widest range of human needs, the waters of the State must be maintained as clean as possible.
2. It should be the responsibility of the water user to return the water as clean as it is technically possible.
3. Beneficial uses of a water must not be destroyed, or even seriously impaired, by a waste discharge.
4. Pollution and contamination are best dealt with at the sources. Treatment of a seriously degraded water even in those cases where possible, and quarantine of contaminated areas, are undesirable alternatives to prevention of water degradation.

areas, are undesirable alternatives to prevention of water degradation.

5. The most complete and efficient types of sewage treatment utilized today do not, of themselves, produce from sewage, water that is restored to its original quality. Natural purification and dilution afforded by receiving waters must be available to further reduce concentrations of undesirable constituents. Moreover, on esthetic grounds, the public demands a separation of time and distance between waste discharge and water use.
6. Singular dependence on water treatment or sewage treatment should be avoided. For a high degree of public health protection, there must be reliable and effective treatment of both sewage and water.
7. Water and sewage treatment are not infallible. Treatment processes for both water and sewage are subject to mechanical failure and human error.
8. Sudden and unexpected changes in raw water quality are likely to upset water treatment processes to a degree such that the plant may fail to produce an acceptable quality water.
9. With relation to many taste- and odor-producing substances, seriously degraded waters usually cannot be returned to a high quality condition by even the most complete water treatment processes generally utilized.
10. A water quality management program, to be successful, must be based on engineering studies and evaluations of all

through adequate water treatment makes possible the maintenance of a high level of water quality in all the waters of the State.

The U. S. Public Health Service Drinking Water Standards of 1946 are used as a quality standard for public water supplies in California. The Drinking Water Standards include maximum allowable and maximum suggested values for physical, chemical, and bacteriological qualities of the water. The 1946 standards and the chemical standards are summarized in Table A.

Table A

CHEMICAL LIMITS
U. S. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS

	Recommended Maximum Limits(1) (milligrams per liter)		Concentrations which constitute grounds for rejection of supply (milligrams per liter)	
	1946	1962(3)	1946	1962(3)
Alkyl benzene sulfonate (Detergent)	-	0.5		
Arsenic	-	0.01	0.05	0.05
Barium			-	1.0
Cadmium			-	0.01
Carbon chloroform extract (exotic organic chemicals)	-	0.2		
Chloride	250.	250.		
Chromium			0.05	0.05
Copper	3.0	1.0		
Cyanide	-	0.01		0.2
Fluoride	-	(2)	1.5	(2)
Iron + manganese	0.3	-		
Iron	-	0.3		
Lead			0.1	0.05
Manganese	-	0.05		
Nitrate	-	45.		
Phenols	0.001	0.001		
Selenium			0.15	0.01
Silver			-	0.05
Sulfate	250.	250.		
Total dissolved solids	500.	500.		
Zinc	15.	5.		

(1) Concentrations in water should not be in excess of these limits, when more suitable supplies can be made available.
(2) Maximum levels of fluoride concentrations are related to average air temperatures. See text of proposed standards.
(3) Proposed.

In determining the degree of treatment required for any particular source of domestic water, major dependence lies with the sanitary evaluation of the watershed; however, raw water quality guides are a useful tool in the evaluation. Based on the operating records of Ohio River water treatment plant, Streeter has proposed a guide for the maximum degree of coliform bacteria that can be accepted by various water treatment methods if the treated water is to meet the standards of the U. S. Public Health Service. The 1946 guide is presented in Table B.

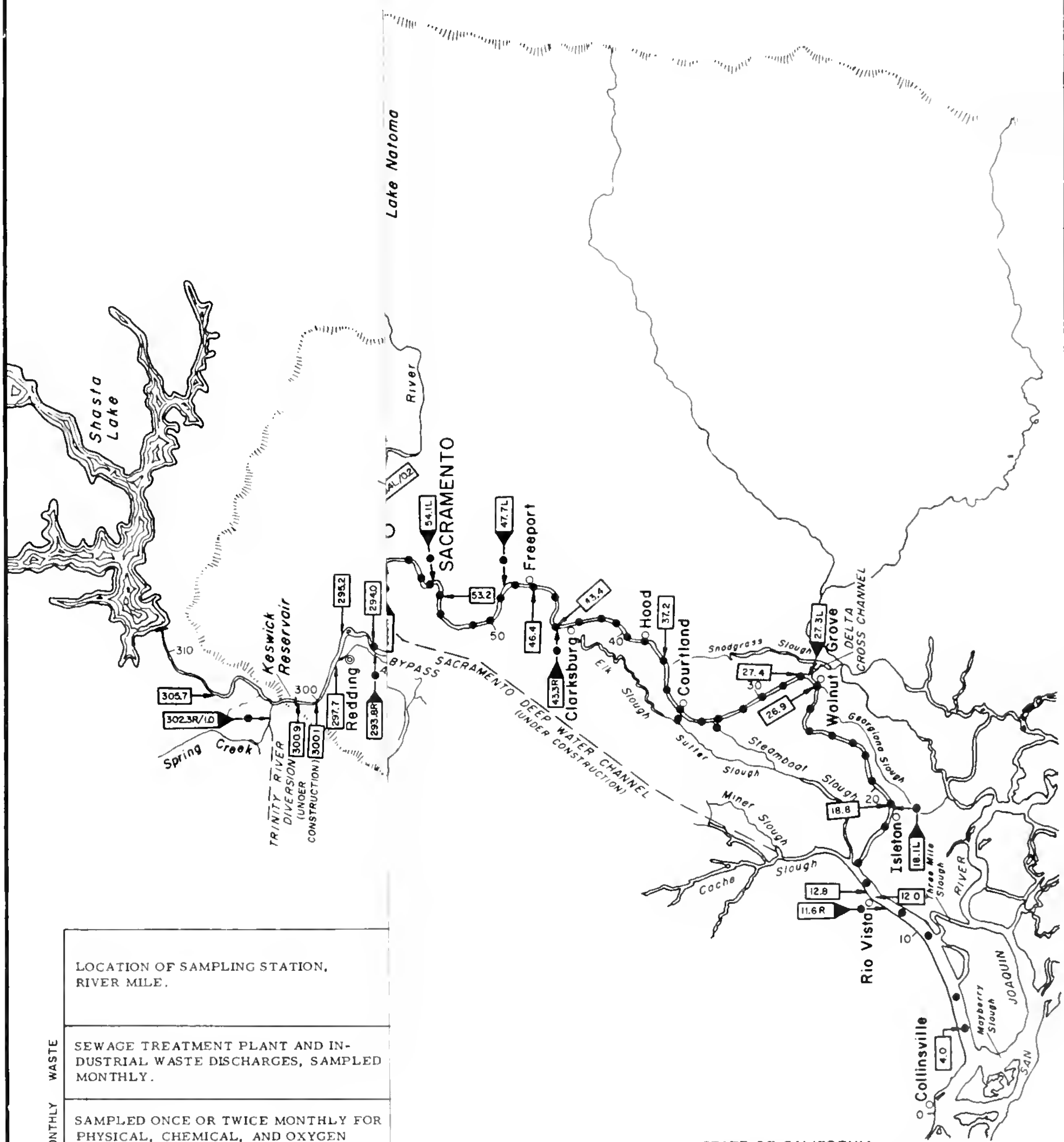
Table B

RAW WATER BACTERIOLOGICAL LIMITS FOR VARIOUS TYPES OF WATER TREATMENT

Monthly Average Coliform MPN/100 ml	Limits of Variability	Treatment Method
50	None	Chlorination
5,000	Not more than 5,000/100 ml in more than 20% of monthly samples.	Filtration and Postchlorination
5,000	More than 5,000/100 ml in more than 20% of monthly samples but not more than 20,000/100 ml in more than 5% of monthly samples.	Presedimentation, prechlorination or their equivalent, filtration and postchlorination.
More than 5,000	None	Prolonged preliminary storage or other reliable measures in addition to prechlorination, filtration and postchlorination.

The State Board of Public Health has not yet adopted bacteriological standards for irrigation water, except those in the board's regulations governing the direct use of sewage effluents for crop irrigation. Also, no bacterial standards have been established for fresh

water recreation areas. The present bacteriological methods of water analyses can not in themselves be used to evaluate its safety for recreation or irrigation. Bacteriological quality is an important parameter, but the acceptance or rejection of a water for irrigation or for water-contact sports must depend on a complete sanitary engineering appraisal of all factors influencing water quality.



	LOCATION OF SAMPLING STATION, RIVER MILE.
WASTE	SEWAGE TREATMENT PLANT AND INDUSTRIAL WASTE DISCHARGES, SAMPLED MONTHLY.
MONTHLY	SAMPLED ONCE OR TWICE MONTHLY FOR PHYSICAL, CHEMICAL, AND OXYGEN ANALYSES.
DAILY	SAMPLED MONTHLY OR BIMONTHLY FOR PLANKTON, BOTTOM ORGANISMS, SEDIMENT GRADATION, DISSOLVED OXYGEN AND TEMPERATURE.
BIOLOGIC	SAMPLED DAILY FOR TEMPERATURE AND ELECTRICAL CONDUCTANCE. CHEMICAL ANALYSES OF COMPOSITE SAMPLES.
ORGANIC	PERIODIC ORGANIC ANALYSES SAMPLING USING CARBON ADSORPTION METHOD.
E C	CONTINUOUS ELECTRICAL CONDUCTIVITY RECORDER.

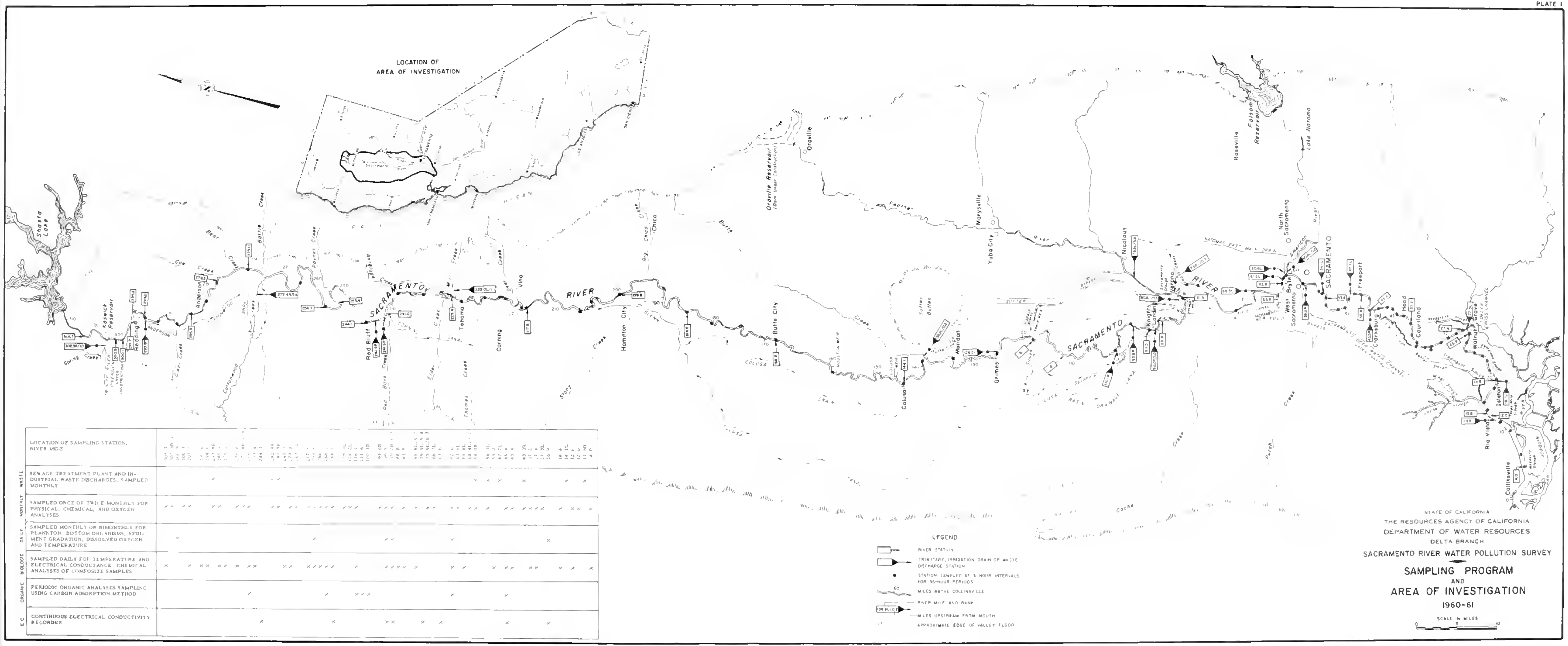
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DELTA BRANCH

SACRAMENTO RIVER WATER POLLUTION SURVEY

SAMPLING PROGRAM
AND
AREA OF INVESTIGATION

1960-61

SCALE IN MILES
0 5 10



	LOCATION OF SAMPLING STATION, RIVER MILE
WASTE	SEWAGE TREATMENT PLANT AND INDUSTRIAL WASTE DISCHARGES, SAMPLED MONTHLY
MONTHLY	SAMPLED ONCE OR TWICE MONTHLY FOR PHYSICAL, CHEMICAL, AND OXYGEN ANALYSES
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ORGANIC	PERIODIC ORGANIC ANALYSES SAMPLING USING CARBON ADSORPTION METHOD
E.C.	CONTINUOUS ELECTRICAL CONDUCTIVITY RECORDER

LEGEND

- RIVER STATION
- TRIBUTARY, IRRIGATION DRAIN OR WASTE DISCHARGE STATION
- STATION SAMPLED AT 3 HOUR INTERVALS FOR 96-HOUR PERIODS
- 160 MILES ABOVE COLLINSVILLE
- RIVER MILE AND BANK
- 138.9L/0.2 MILES UPSTREAM FROM MOUTH
- APPROXIMATE EDGE OF VALLEY FLOOR

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SACRAMENTO RIVER WATER POLLUTION SURVEY

SAMPLING PROGRAM AND AREA OF INVESTIGATION

1960-61

SCALE IN MILES
0 5 10

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SACRAMENTO RIVER WATER POLLUTION SURVEY

TRIBUTARY BASINS OF SACRAMENTO RIVER

1960-61

SCALE OF MILES
8 0 8 16 24

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SACRAMENTO RIVER WATER POLLUTION SURVEY

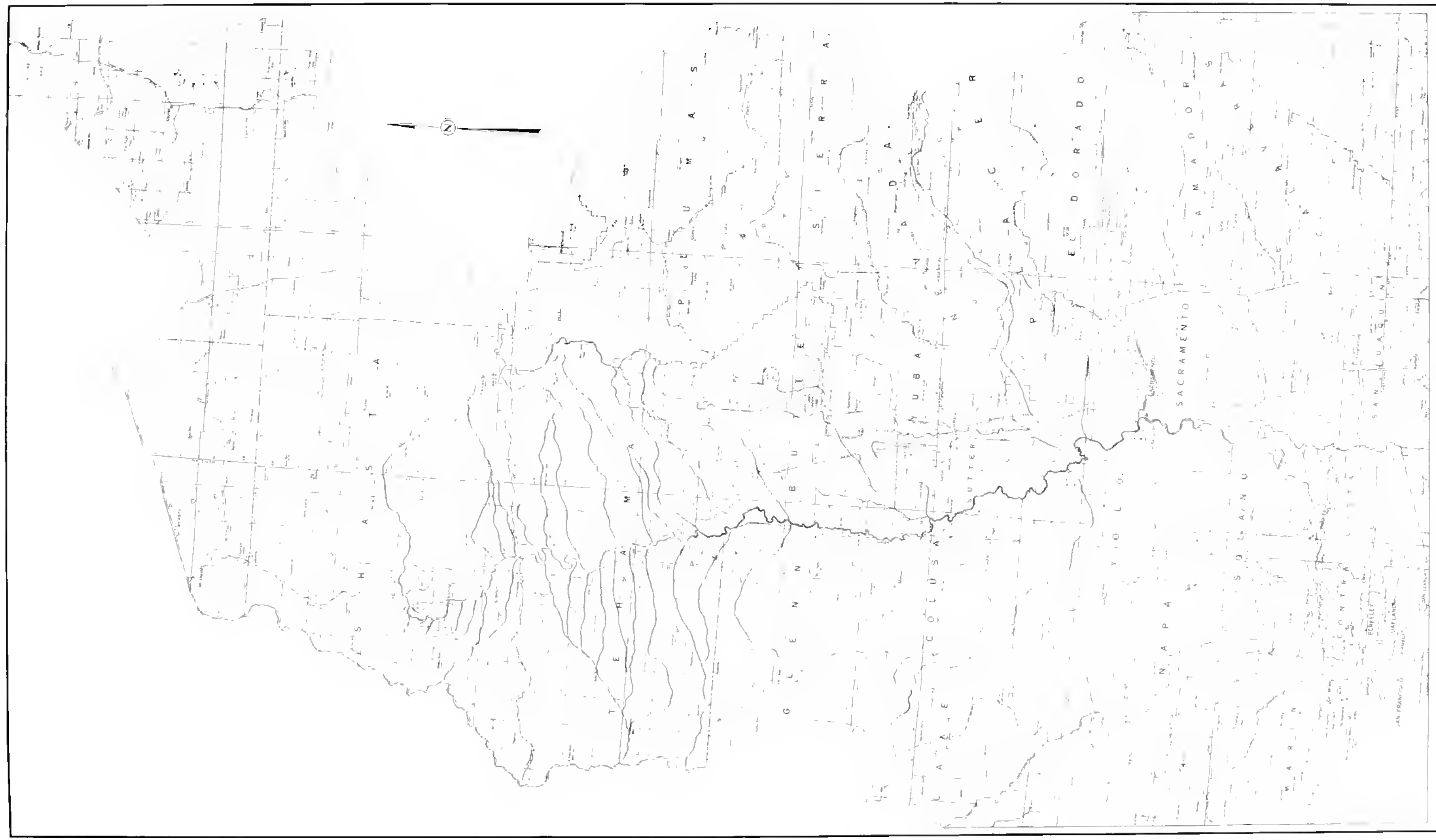
TRIBUTARY BASINS OF SACRAMENTO RIVER

1960-61

SCALE OF MILES
8 0 8 16 24

PLATE 2

LEGEND



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SACRAMENTO RIVER WATER POLLUTION SURVEY

TRIBUTARY BASINS OF SACRAMENTO RIVER

1960-61

SCALE OF MILES

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